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LEVEL

ENGINEERING AND DESIGN COST/RATE FORECASTING SYSTEM, VOLUME I: MODEL DEVELOPMENT AND DATA ANALYSIS

Final rept.,

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by
Robert R. D. Neathammer

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COMPUTER PROGRAM DATA SHEET

Title: Engineering and Design (E&D) Cost/Rate Forecasting System

Proponent: Directorate of Military Construction Data Processing Instal-
lation: Construction Division of MC Operations and Planning Branch

Language: BASIC

Hardware: TEKTRONIX 4051

Availability: Corps of Engineers Engineering Computer Programs Library

This report discusses the development of statistically based models for forecasting engineering and design (E&D) costs in order to establish military construction cost targets for Corps of Engineers Districts and Divisions. The model developed is programmed on the TEKTRONIX 4051 graphics system in the Office of the Chief of Engineers (OCE). When the model was verified, only one of 18 predictions was outside the predic-

Block 20 continued.

E/D

—tion limits (95 percent confidence). The model is best used to project E&D costs 1 year in advance, and it is recommended that it be used to help establish cost targets for applicable Corps Divisions/Districts.

This report contains two volumes. Volume I presents results of the research study and Volume II is the User's Manual for the TEKTRONIX 4051 program.

FOREWORD

This research was conducted for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under O&MA FAD No. 78-1, dated 1 October 1977, and FAD Change No. 1, dated 29 November 1977. The OCE Technical Monitor was Mr David Spivey, DAEN-MCC-C.

The work was performed by the Facility Systems Division (FS), U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. The principal investigator was Mr. Robert Neathammer. Mr. E. A. Lotz is Chief of FS.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES.

FIGURES.

FIGURES (cont'd)

ENGINEERING AND DESIGN COST/RATE
FORECASTING SYSTEM--VOLUME I.
MODEL DEVELOPMENT AND DATA ANALYSIS

1 INTRODUCTION

Background

The Directorate of Military Construction (DMC) of the Office of the
Chief of Engineers (OCE) annually establishes engineering and design
(E&D) cost targets for military construction for each Corps of Engineers
Division/District. These targets, expressed as a percentage of the
dollar value of construction designed, are currently established by an
empirical procedure based on the previous 4 to 5 years of Division/Dis-
trict performance and the estimated cost of construction (ECC) for the
next fiscal year. Previous work[1] has shown that statistical analysis
methods can be used to predict future E&D costs for individual Di-
visions/Districts using historical data. OCE requested that CERL de-
velop similar methods for predicting contract and in-house E&D costs.
Use of such methods to develop mathematically valid forecast models
would result in more reliable and precise forecasts. Such forecasts
should have an accuracy of ±10 percent.

Objective

The objective of this study is to develop statistically based
models for forecasting E&D in-house and contract costs separately; these
predictions will help DMC establish E&D cost targets for each
Division/District.

Approach

Available data for the pertinent variables was obtained and re-
viewed and a model relating these variables was postulated; regression
analysis was used to fit the model to the data. Finally, the model's
capability of accurately forecasting E&D rates was determined.

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[1] M. J. O'Connor, G. J. Brown and J. R. DeCardy, *Military Construction
Engineering and Design Forecasts,* Technical Report P-77/ADA035262 (U.S.
Army Construction Engineering Research Laboratory [CERL], January
1977).

2 METHOD OF DATA REVIEW

E&D cost data were abstracted from the OCE "Program Review and Analysis: Division and District Performance Data Reports" for the 9-year period from FY69 through FY77 (see Appendix A). Prior to FY71, the ECC was defined as 85 percent of the programmed cost; if the programmed cost was not established, the ECC was the equivalent cost. In the second quarter of FY71, this percentage was changed to 90 percent. The FY69 and FY70 data were adjusted to conform to the post-FY70 definition. In addition, data for the Baltimore and Omaha Districts were adjusted for the years when they absorbed E&D work from the Norfolk and Kansas City Districts. Appendix B provides information about these adjustments.

CERL Report P-77 used data available through FY66 for analysis. These analyses related the District yearly total E&D costs to ECC. For the present study, the total E&D costs were split into in-house (INHED) and contract (AEED) costs for analysis purposes. It was not possible to split FY66, FY67, and FY68 E&D costs into INHED and AEED; therefore, a maximum of 9 years' data was available.

Data for the following Divisions/Districts were not analyzed, since less than 9 years of data were available for them:

1. European Division
2. Huntsville Division
3. Kansas City District
4. Norfolk District
5. Los Angeles District.

The Mediterranean Division and the Middle East Division were eliminated because the recent Saudi Arabian Government workload has distorted their historical data. The following Divisions/Districts had sufficient data for analysis:

1. Alaska District
2. Baltimore District
3. Fort Worth District
4. Mobile District
5. New York District
6. Omaha District
7. Pacific Ocean Division
8. Sacramento District
9. Savannah District.

3 MODEL DEVELOPMENT AND DATA ANALYSIS

CERL Report P-77 showed that the following model was appropriate:

$$D_i = b_{0i} + b_{1i}C + b_{2i}T + b_{3i}TC \qquad \text{(Eq 1)}$$

where D_i = predicted E&D costs for the ith Division/District ($ MIL)
  C = estimated cost of construction ($ MIL)
  T = time period (FY69=1, FY70=2...)
  $TC = T \times C$
  $b_{0i}, b_{1i}, b_{2i}, b_{3i}$, = coefficients for the ith Division/District.

This model was found satisfactory for estimating both in-house and contract E&D costs. Thus, for each District:

$$INHED_i = b_{0i} + b_{1i}C + B_{2i}T + B_{3i}TC$$

$$AEED_i = b'_{0i} + b'_{1i}C + b'_{2i}T + b'_{3i}TC$$

where $INHED_i$ = in-house E&D cost for ith Division/District

  $AEED_i$ = contract E&D cost for ith Division/District

  $b_{0i}, b_{1i}, b_{2i}, b_{3i}$ = coefficients for in-house costs for the ith Division/District

  $b'_{0i}, b'_{1i}, b'_{2i}, b'_{3i}$ = coefficients for contract costs for the ith Division/District

E&D rates are defined as

  $INHR_i = 100 \times INHED_i/C$ = in-house rate for the ith Division/District

  $AEED_i = 100 \times AEED_i/C$ = contract rate for the ith Division/District

Regression analyses showed significant differences among Divisions/Districts for both in-house and contract E&D costs. Each model used significantly different coefficients; i.e., no one set of coefficients can be used for all Divisions/Districts. This means that the total data cannot be pooled to determine one set of coefficients. Instead, Division/Districts must be put into homogeneous groups, or

9

treated individually. Since it would be very difficult to use the TEK-TRONIX 4051* to check for homogeneous groupings as additional years' data are added, a model was developed for each Division/District.

In addition to the model of Eq 1, another model which consisted of Eq 1 plus a T^2** term was examined. Graphs of E&D costs vs. time (Appendix B) indicated that for some Divisions/Districts, such a quadratic effect over time might explain a large part of the data variation. However, analysis showed that the basic model (Eq 1) was adequate.

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* The model developed is programmed for use by DMC personnel on the TEKTRONIX 4051 graphics system in OCE.
**A quadratic term in time.

4 MODEL RESULTS AND VERIFICATION

Results

The model provided good estimates of AEED costs for most Districts and good estimates of total E&D costs for all Districts; however, for all Divisions/Districts, the model provided only fair estimates of INHED costs. This was expected, since INHED costs are affected by staffing limitations and the quantity of work other than E&D and are thus highly constrained. AEED costs and total costs can more readily vary with changes in the ECC.

Table 1 shows the regression results for the nine Divisions/Districts. In each case, the best model for AEED, INHED, and total E&D costs is given with the standard error of estimate and the square of the multiple correlation coefficient (R^2).*

Criteria for a good model are (1) that $R^2 \geq .90$, and (2) the standard error <10 percent of the data average (i.e., coefficient of variability <10 percent). For contract E&D costs, models for two Districts failed the R^2 criterion, while five failed the coefficient of variability criterion. For in-house costs, the best models for all Districts failed both criteria. Models for total E&D costs fared better; the model for one District failed both criteria, but all the other District models passed. This means that the models for in-house costs generally will not forecast future years' costs as well as the models for contract and total costs.

Figures 1 through 9 show the FY78 prediction equations and graphs. The prediction limits indicate the accuracy of the prediction. For example, for Baltimore District (Figure 2), if the estimator assumes an ECC of $150 million in FY78, he/she can be 95 percent confident that the contract E&D cost will range between $6.1 and $7.4 million and that the in-house E&D cost will range between $.8 and $1.8 million. Correspondingly, the contract E&D rate will range between 4.1 and 4.8 percent, and the in-house E&D rate will range between .6 and 1.2 percent.

The in-house and contract rates are based on the total ECC. It is not possible to separate the ECC for which E&D was done in-house from ECC for which E&D was contracted. Thus, the contract and in-house E&D percentages (rates) in this report are based on the *total* ECC. Such a

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*The standard error is a measure of the amount of variation of the data about the prediction model. R^2 is the multiple correlation coefficient squared; when multiplied by 100, it is the percent of the variation in the data which is explained by the model.

Table 1

Regression Results
E&D Cost = $b_0 + b_1 C + b_2 T + b_3 CT$

Div/District	b_0	b_1	b_2	b_3	Standard Error of Estimate, S ($ MIL)	Coefficient of Variability (%)	Percent of Variance of Original Data Explained by Model $R^2/100$
Contract E&D							
Alaska	-.076			.00424	.126	25.9*	.947
Baltimore	-.217	.0461			.182	3.8	.993
Fort Worth	-1.432	.0512			.560	8.3	.987
Mobile	.463			.00544	.455	12.4*	.971
New York	-.341	.0537			.243	12.9*	.837**
Omaha	-.200	.0388	-.604	.00535	.520	9.1	.996
Pacific Ocean Div.	-.066	.0330			.468	16.8*	.882**
Sacramento	-.402	.0498			.212	5.2	.992
Savannah	2.061		-.717	.00844	.422	11.2*	.987
In-House E&D							
Alaska	1.331		-.239	.00619	.180	16.8*	.687**
Baltimore	.869	-.0054	-.124	.00084	.120	14.8*	.781**
Fort Worth	2.570				.416	21.3*	.433**
Mobile	.917	.0168		-.00168	.253	15.8*	.555**
New York	.979	-.0068	.863		.287	41.1*	.056**
Omaha	.791		-.381	-.00497	.597	41.1*	.782**
Pacific Ocean Div.	3.805				.903	47.5*	.604**
Sacramento	1.384		-.208	.00146	.194	16.7*	.701**
Savannah	1.788	-.0046			.256	19.4*	.518**
Total E&D							
Alaska	1.267		-.245	.01056	.080	5.5	.989
Baltimore	.678	.0399		.00094	.190	3.4	.994
Fort Worth	1.130	.0469			.321	4.0	.994
Mobile	2.217			.00519	.429	8.1	.972
New York	.638	.0469			.119	4.6	.943
Omaha	.484	.0400	.307		.243	3.4	.995
Pacific Ocean Div.	2.567	.0467	-.383		.942	20.1*	.860**
Sacramento	-.312	.0679	-.237		.125	2.4	.998
Savannah	3.398		-.609	.00755	.369	7.3	.988

Note: The standard error is a measure of the amount of variation of the
data about the prediction model. R^2 is the multiple correlation
coefficient squared; when multiplied by 100, it is the percent of the
variation in the data which is explained by the model.
* The coefficient of variability is greater than .10.
** The R^2 is less than .90.

separation and regression of INHED and AEED in terms of the appropriate ECC is desirable, since such models should be more accurate.

A number of different options could be tried to get the appropriate mix of in-house versus contract design but the model has not accurately depicted conditions at the lower range for in-house effort. Therefore extreme caution should be used if this is attempted.

The prediction limit graphs are plotted over reasonable ranges of ECC for each District. It would not be correct to use the graphs if the next year's ECC is expected to be two or three times larger than the ECC for FY77 or if it is expected to be only one-half or one-fourth as large; i.e., such drastic changes in ECC would require the Division/District to operate differently than in the past few years, and the model would not reflect this change adequately.

Verification

The 8 years of data from FY69 through FY76 were used to generate regression coefficients and to predict the FY77 E&D costs. Table 2 shows the results of this verification. Note that only one of 18 predictions was outside the 95 percent prediction limits. However, some of the limits are very wide because of high variability of data within a District/Division. (Note: the verification analysis was performed using the full model [Eq 1]).

The model's predictions are much more accurate for contract costs than for in-house costs. This is obvious by how much the FY78 predicted value deviates from the actual value. —

In Table 2, the percent deviations of the predicted FY77 E&D costs from the actual costs show that the in-house models are not very accurate (8 of the 9 predictions deviated by more than 10 percent). Five of the nine contract percent deviations were within 10 percent, while six of the total E&D deviations were within 10 percent (Table 3).

Table 3 shows how well the model, which is based on total E&D costs vs. time a. 1 ECC, predicts the FY77 E&D costs. Note that the sum of the predicted contract and in-house costs from Table 2 is the same as the predicted total E&D costs for each District/Division.

With only 9 years' data available, forecasts for 2 years in advance were not attempted and are not recommended. The model should only be used for forecasts 1 year in advance until at least 11 years' data are available.

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
ALASKA (CONTRACT) - FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 4.24 -7.6/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= -0.076+0.0424*ECC

ECC ($*10**6)
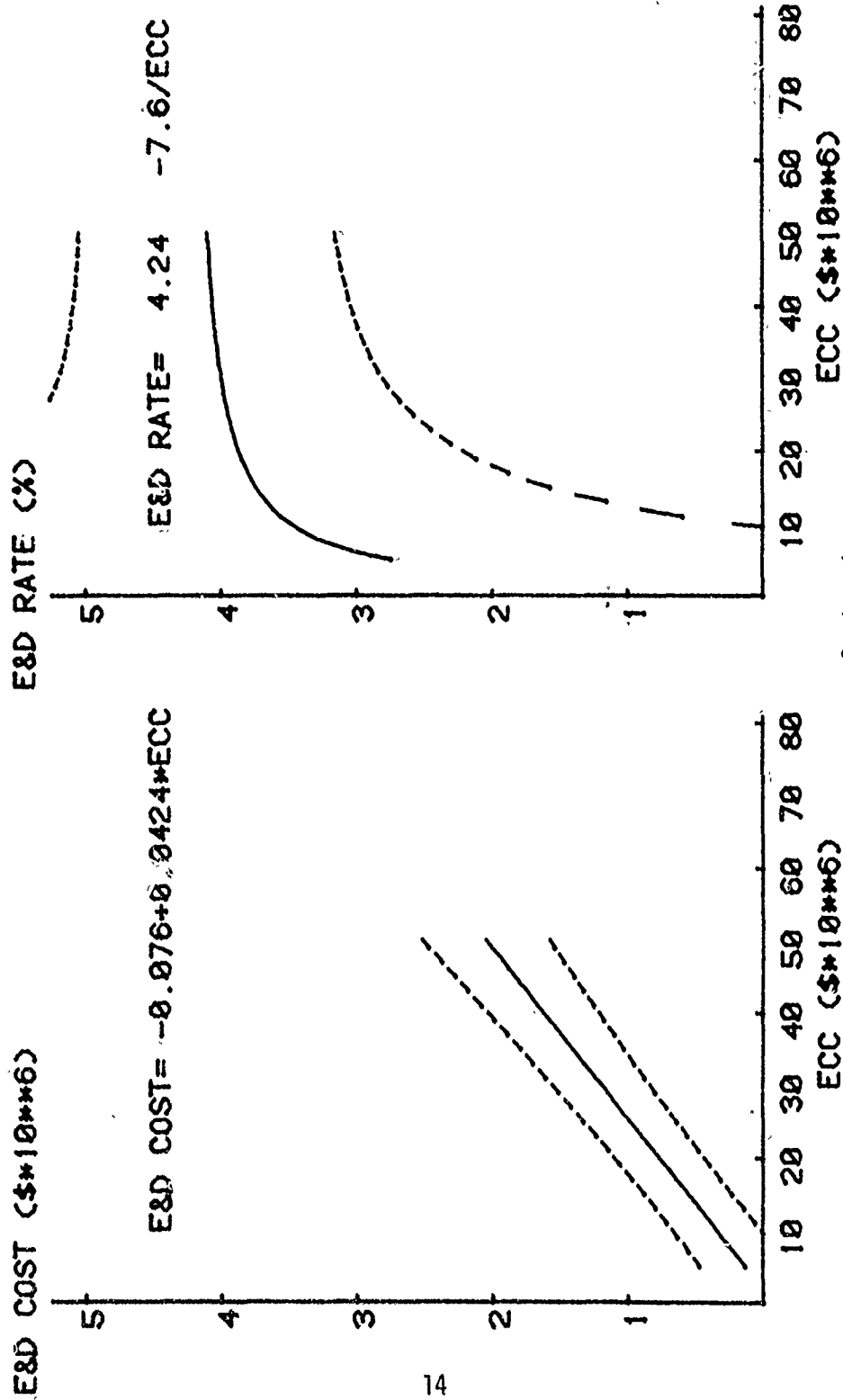
a. Contract

Figure 1. Prediction of E&D Costs/Rates - Alaska - FY78.

14

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
ALASKA (INHOUSE) – FY78
——— PREDICTED VALUE
--- 95% PREDICTION LIMITS
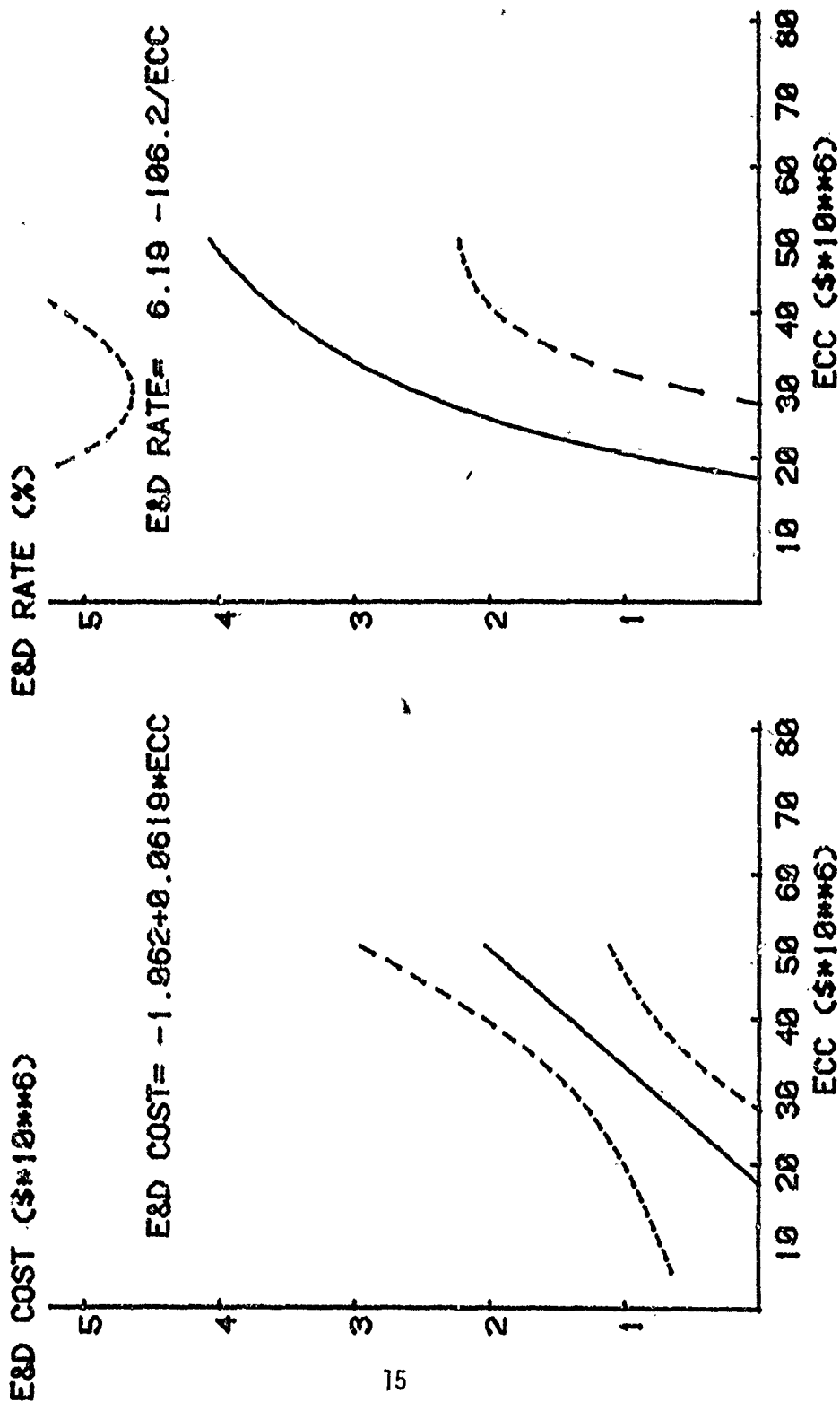
b. In-House

Figure 1 (con't)

15

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
ALASKA (TOTAL) - FY78
——— PREDICTED VALUE
--- 95% PREDICTION LIMITS

c. Total

Figure 1 (con't)

16

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
BALTIMORE (CONTRACT) - FY78
—— PREDICTED VALUE
---- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 4.61 -21.7/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= -0.217+0.0461*ECC

ECC ($*10**6)

a. Contract

Figure 2. Prediction of E&D Costs/Rates - Baltimore - FY78.

17

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
BALTIMORE (IN-HOUSE) - FY78
PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D COST ($*106)**

E&D COST= 0.869+0.0031*ECC

ECC ($*10**6)

E&D RATE (%)

E&D RATE= 0.31 +86.9/ECC

ECC ($*10**6)

b. In-House
Figure 2 (con't)

18

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
BALTIMORE (TOTAL) - FY78
—— PREDICTED VALUE
---- 95% PREDICTION LIMITS

E&D RATE (%)

$E\&D\ RATE = 4.93\ +67.8/ECC$

ECC ($*10**6)

E&D COST ($*10**6)

$E\&D\ COST = 0.678 + 0.0493*ECC$

ECC ($*10**6)

c. Total

Figure 2 (con't)

19

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
FORT WORTH (CONTRACT - FY78

—— PREDICTED VALUE
---- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 5.12 -143.2/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= -1.432+0.0512*ECC

ECC ($*10**6)

a. Contract

Figure 3. Prediction of E&D Costs/Rates - Fort Worth - FY78 .

20

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
FORT WORTH (INHOUSE) - FY78

—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D COST ($*10**6)

E&D COST= 1.329 0.0000*ECC

20
18
16
14
12
10
8
6
4
2

48 80 120 160 200 240 280 320
ECC ($*10**6)

E&D RATE (%)

E&D RATE= 0.00 +132.9/ECC

20
18
16
14
12
10
8
6
4
2

48 80 120 160 200 240 280 320
ECC ($*10**6)

b. In-House.
Figure 3 (con't)

21

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
FORT WORTH (TOTAL) - FY78
——— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 4.69 +113.8/ECC

ECC ($*10**6)
40 80 120 160 200 240 280 320

E&D COST ($*10**6)

E&D COST= 1.138+0.0469*ECC
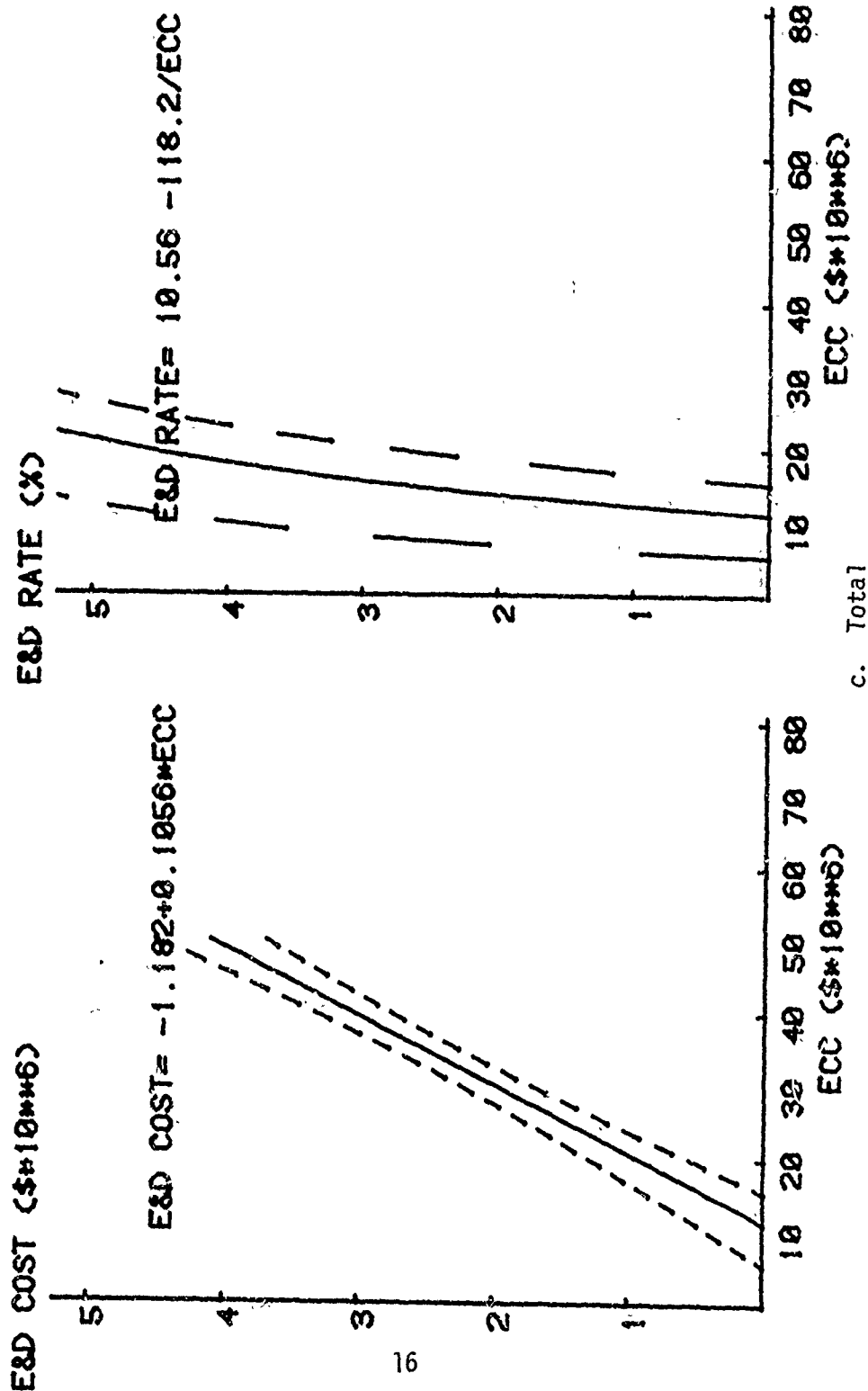
ECC ($*10**6)
40 80 120 160 200 240 280 320

c. Total

Figure 3 (con't)

22

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
MOBILE (CONTRACT) — FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 5.44 +46.3/ECC

10
9
8
7
6
5
4
3
2
1

20 40 60 80 100 120 140 160
ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= 0.463+0.0544*ECC

10
9
8
7
6
5
4
3
2
1

20 40 60 80 100 120 140 160
ECC ($*10**6)

a. Contract

Figure 4. Prediction of E&D Costs/Rates - Mobile - FY78.

23

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
MOBILE (INHOUSE) - FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 0.00 +91.7/ECC

E&D COST ($*10**6)

E&D COST= 0.917 0.0000*ECC
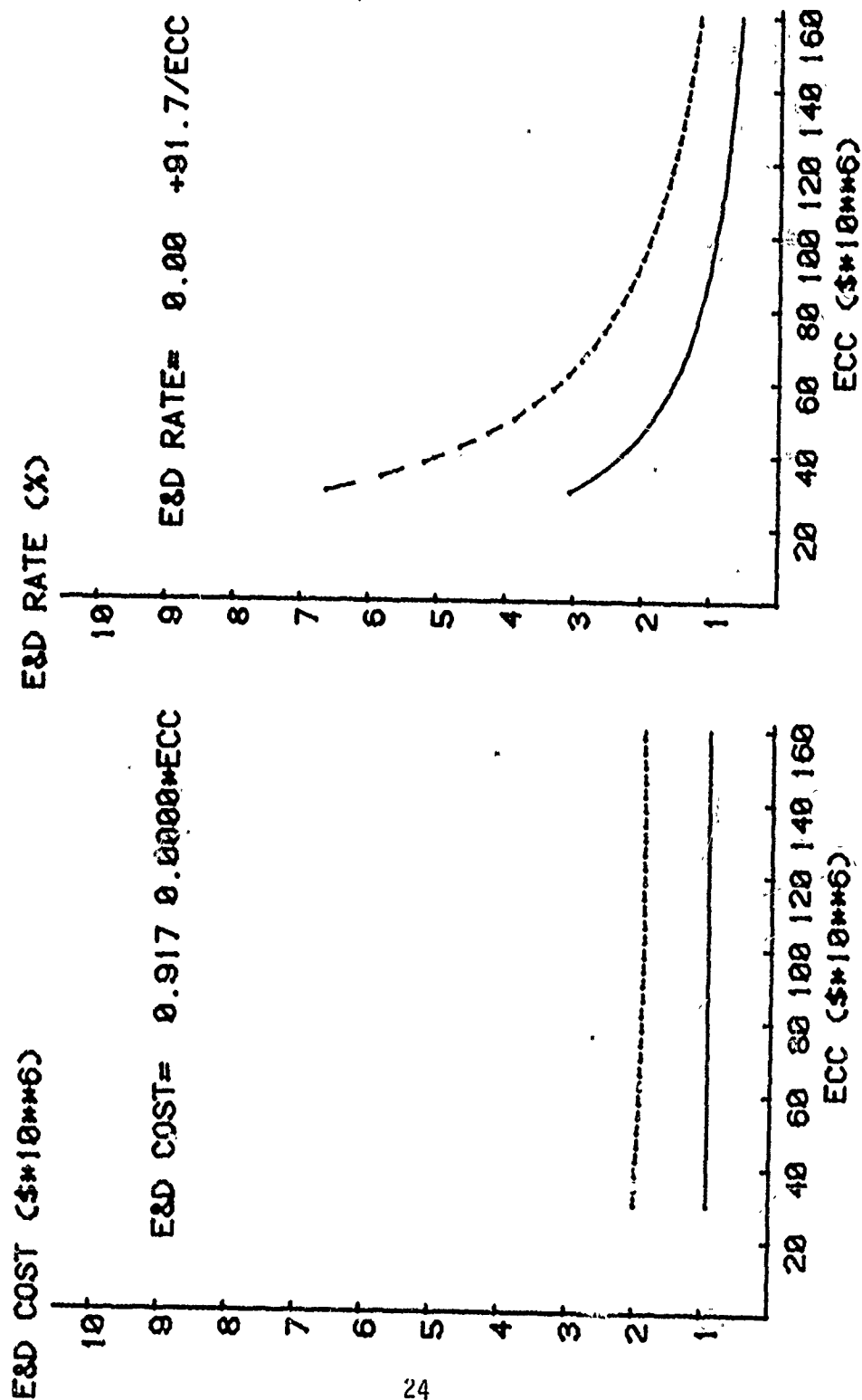
b. In-House
Figure 4 (con't)

24

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
MOBILE (TOTAL) - FY78
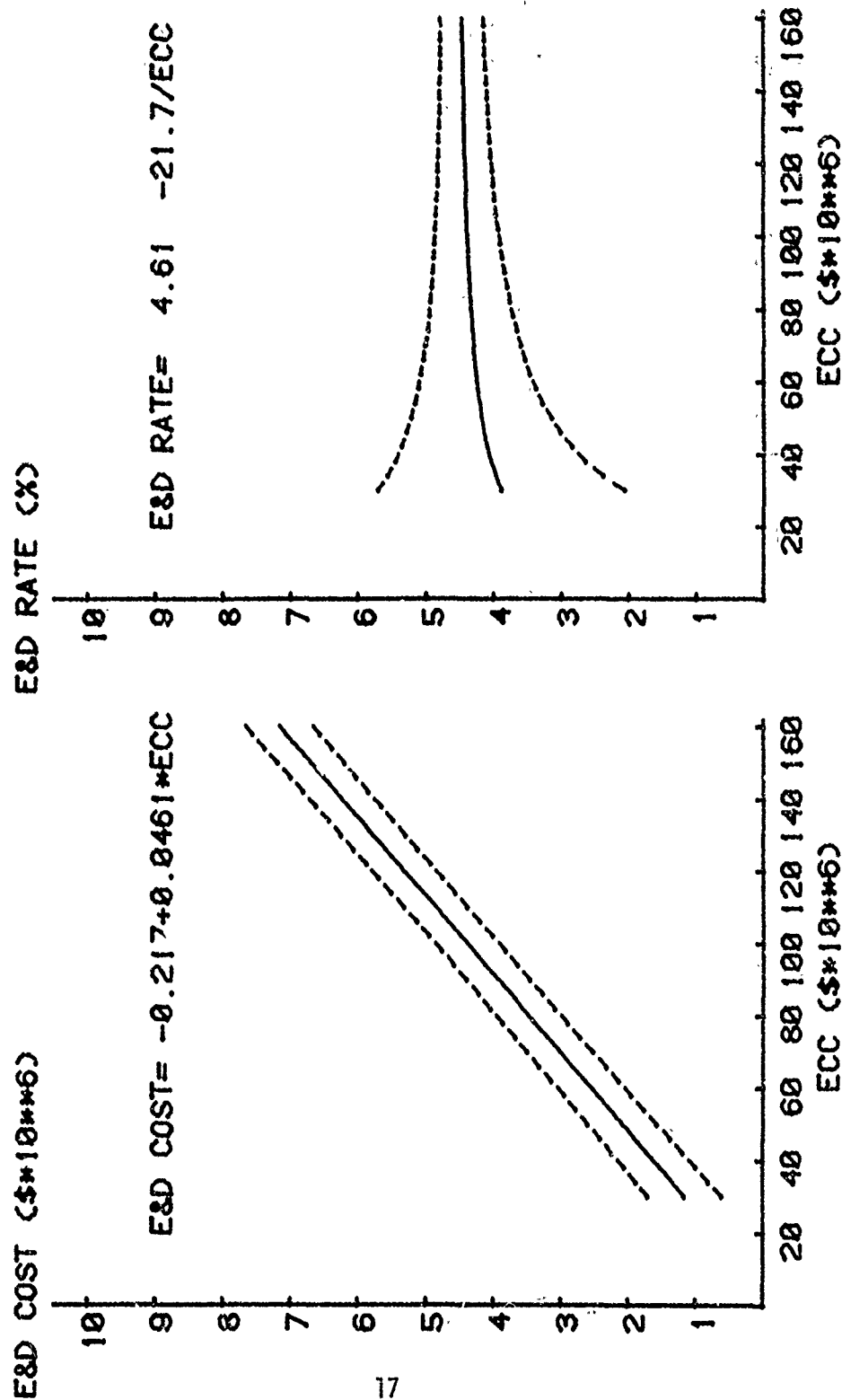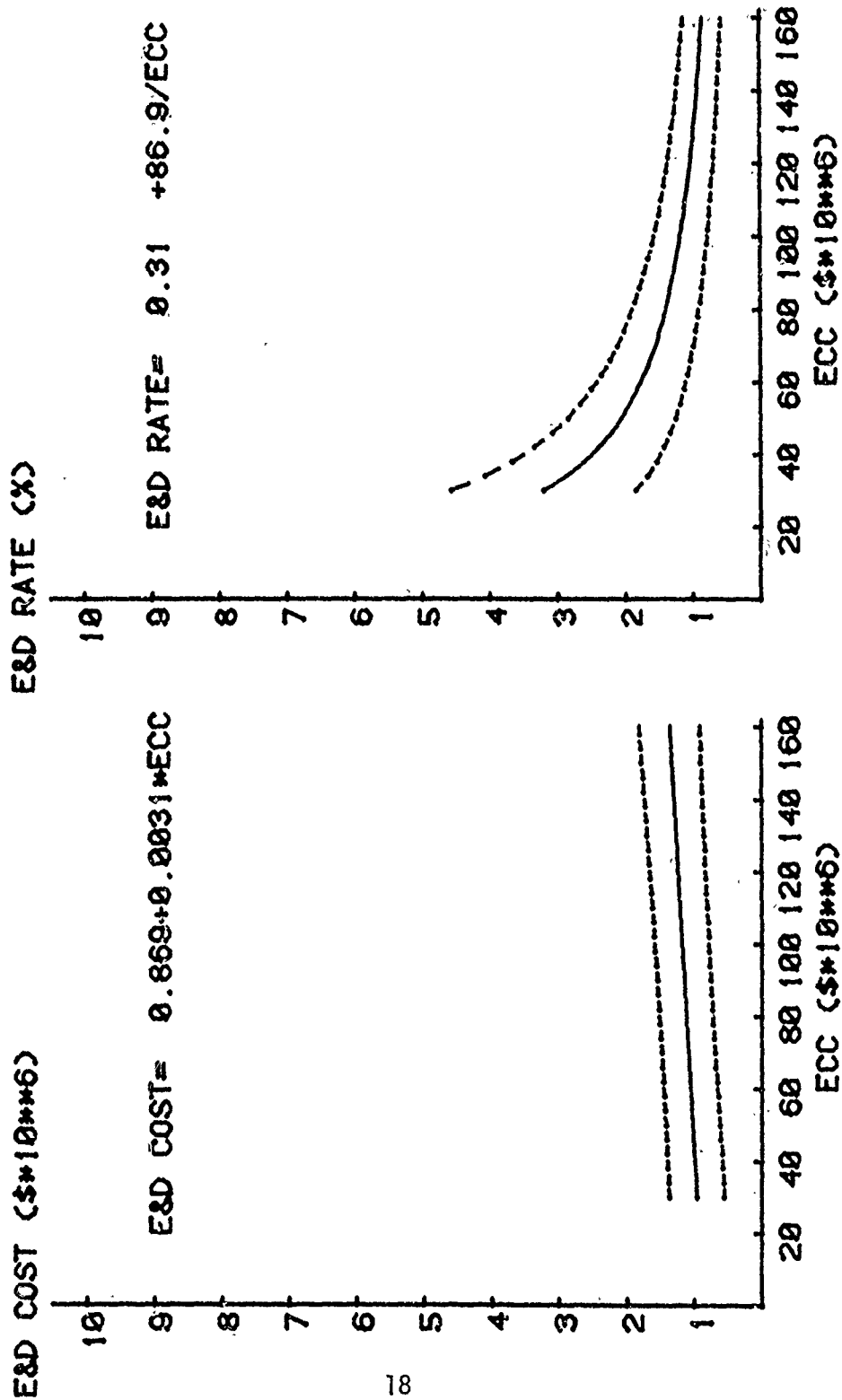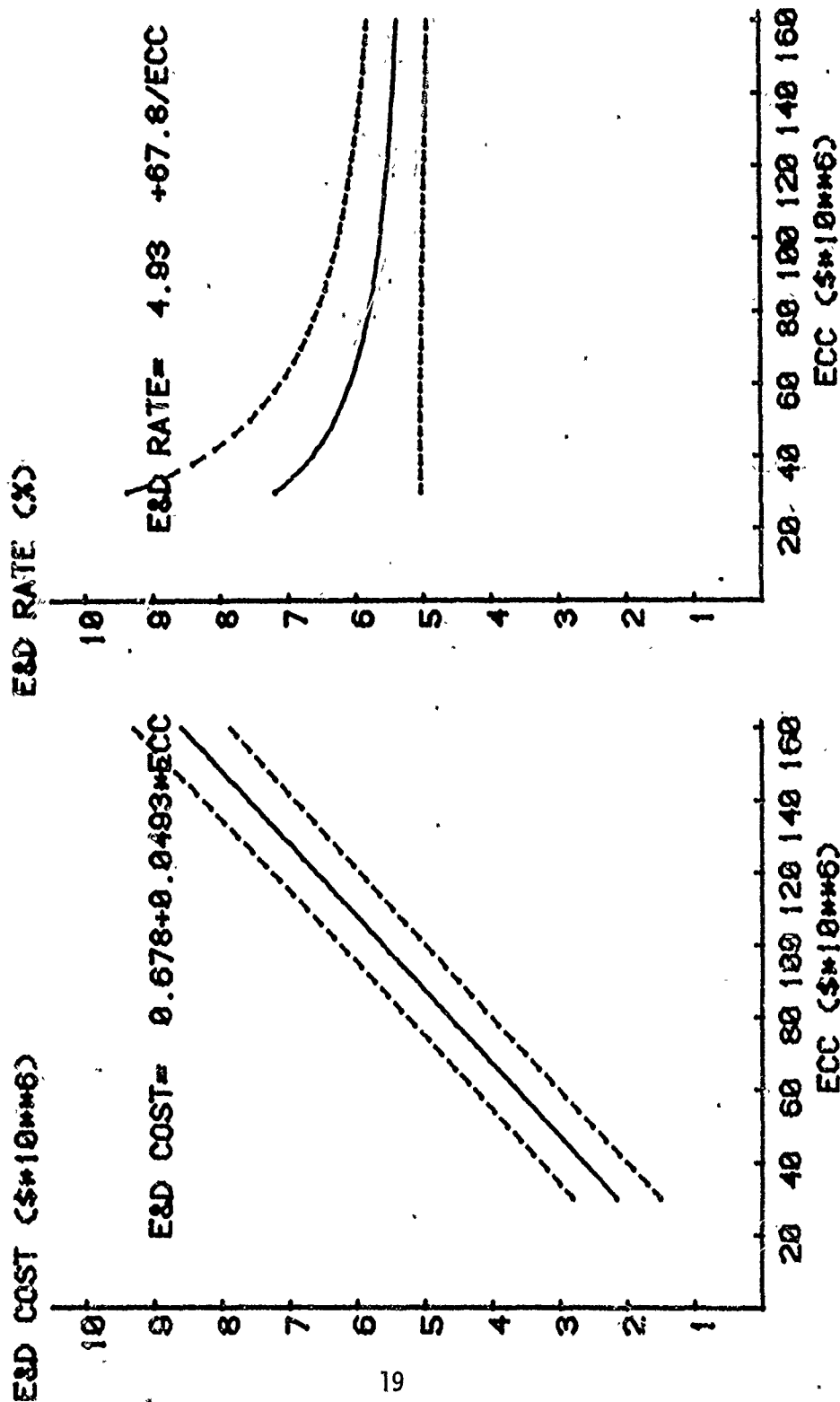—— PREDICTED VALUE
--- 95% PREDICTION LIMITS
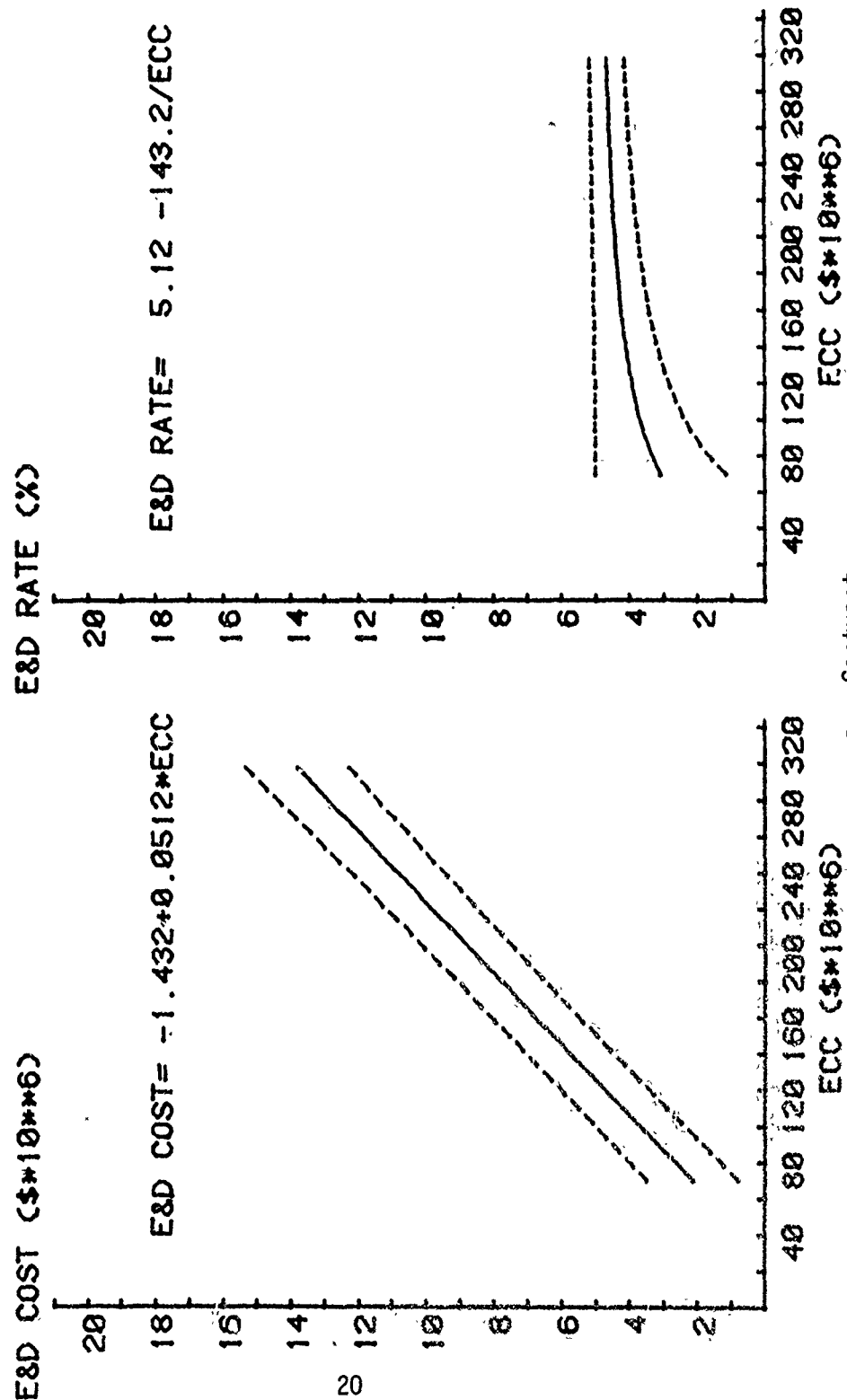
E&D RATE (%)

E&D RATE= 5.19 +221.7/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= 2.217+0.0519*ECC

ECC ($*10**6)

c. Total

Figure 4 (con't)

25

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
NEW YORK (CONTRACT) – FY78
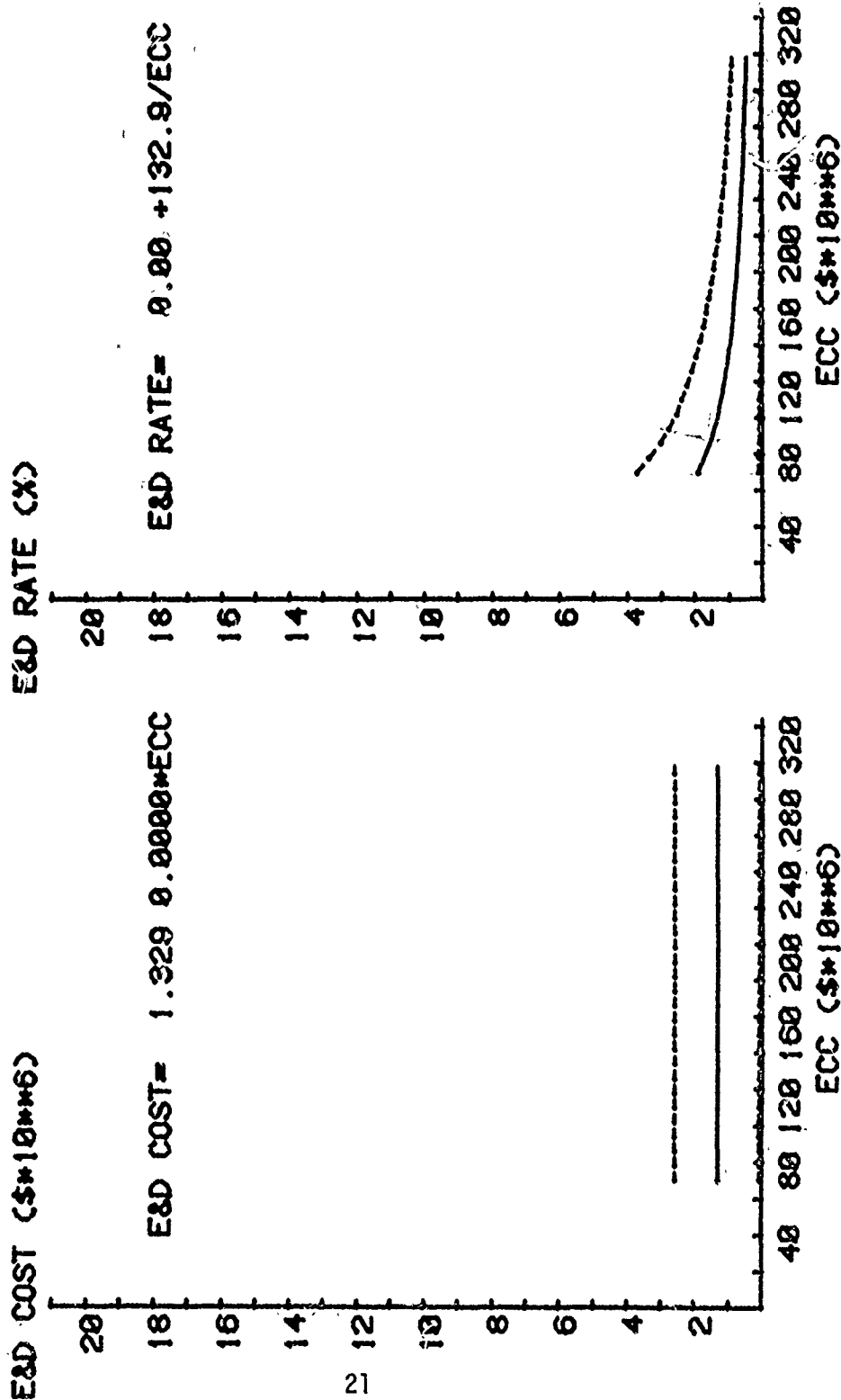
——— PREDICTED VALUE
- - - 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 5.37 -34.1/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= -0.341+0.0537*ECC

ECC ($*10**6)

a. Contract

Figure 5. Prediction of E&D Costs/Rates - New York - FY78.

26

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
NEW YORK (INHOUSE) – FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= -0.68 +97.9/ECC

ECC ($*10**6)

E&D COST ($*106)**

E&D COST= 0.978-0.0068*ECC

ECC ($*10**6)

b. In-House

Figure 5 (con't)

27

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
NEW YORK (TOTAL) - FY78
—— PREDICTED VALUE
---- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 4.69 +63.8/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= 0.638+0.0468*ECC

ECC ($*10**6)

c. Total

Figure 5 (con't)

28

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
OMAHA (CONTRACT) – FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 9.23 –624.3/ECC

ECC ($*10**6)

a. Contract

E&D COST ($*10**6)

E&D COST= -6.243+0.0923*ECC

ECC ($*10**6)

Figure 6. Prediction of E&D Costs/Rates – Omaha – FY78.

29

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
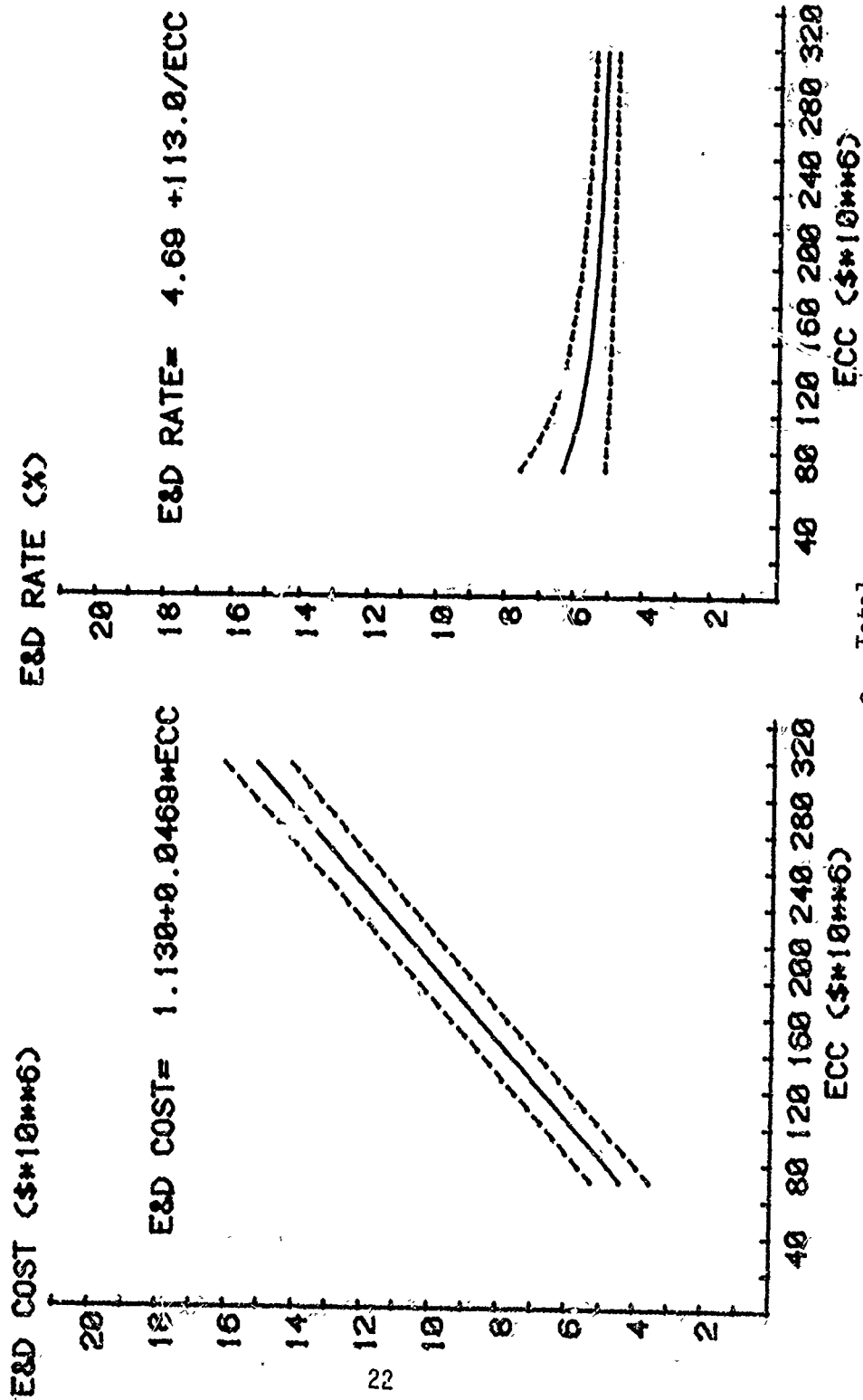## OMAHA (INHOUSE) - FY78

— PREDICTED VALUE
--- 95% PREDICTION LIMITS

$$E\&D\ RATE = -4.97 + 942.5/ECC$$

E&D RATE (%)

ECC ($*106)**

$$E\&D\ COST = 9.425 - 0.0497*ECC$$

E&D COST ($*106)**

ECC ($*106)**

b. In-House

Figure 6 (con't)

30

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
OMAHA (TOTAL) - FY78
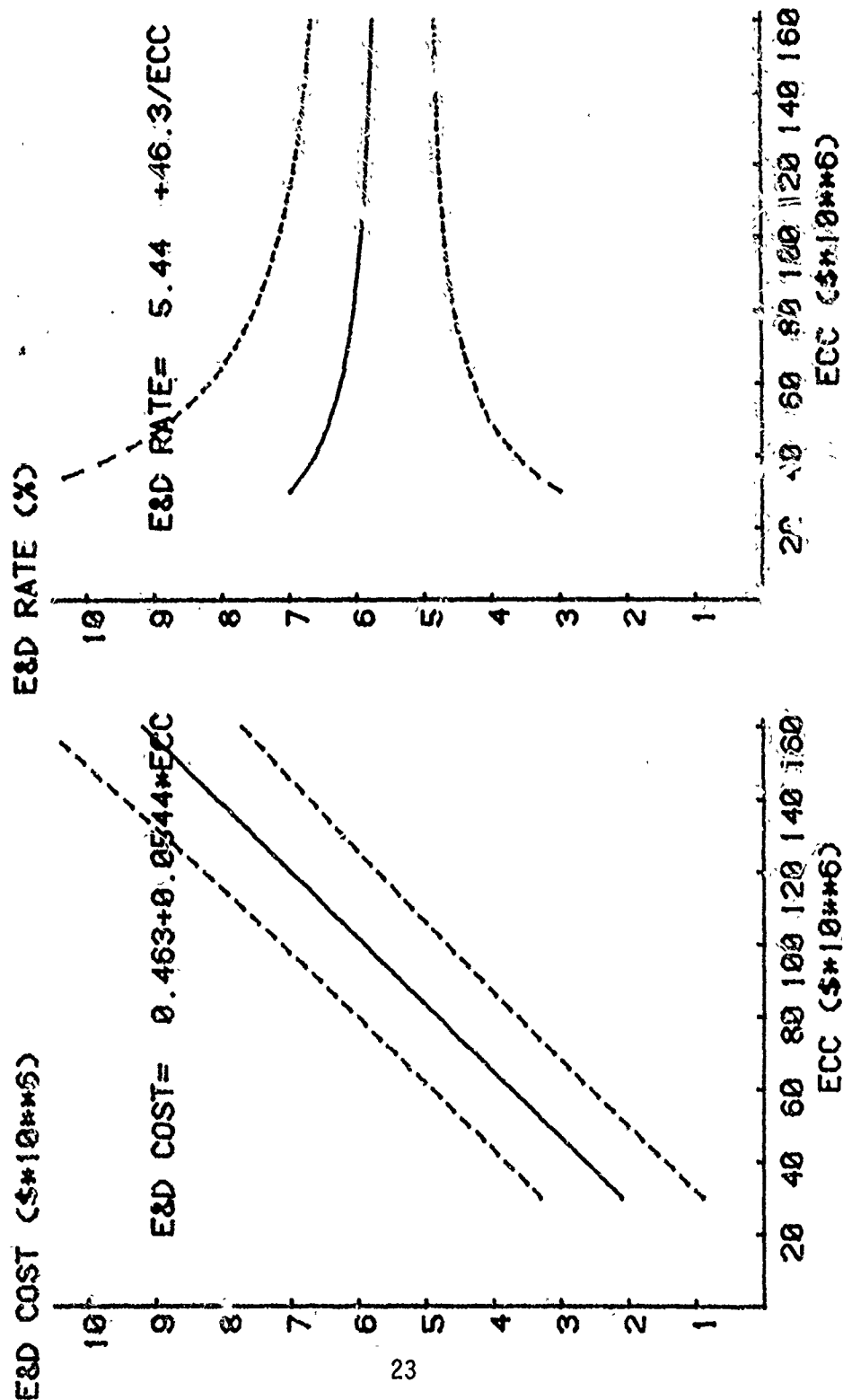—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

c. Total

Figure 6 (con't)

31

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
PACIFIC (CONTRACT) - FY78
—— PREDICTED VALUE
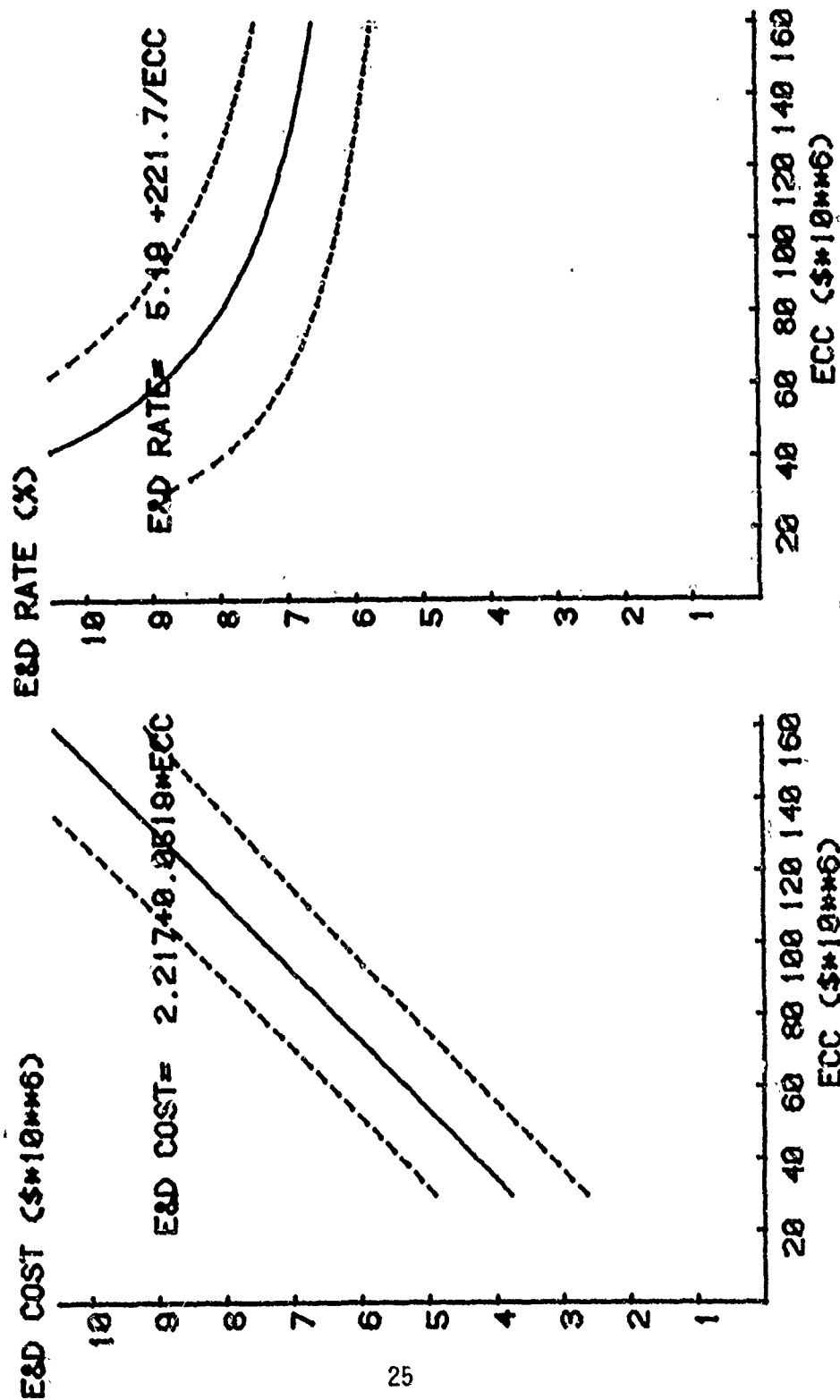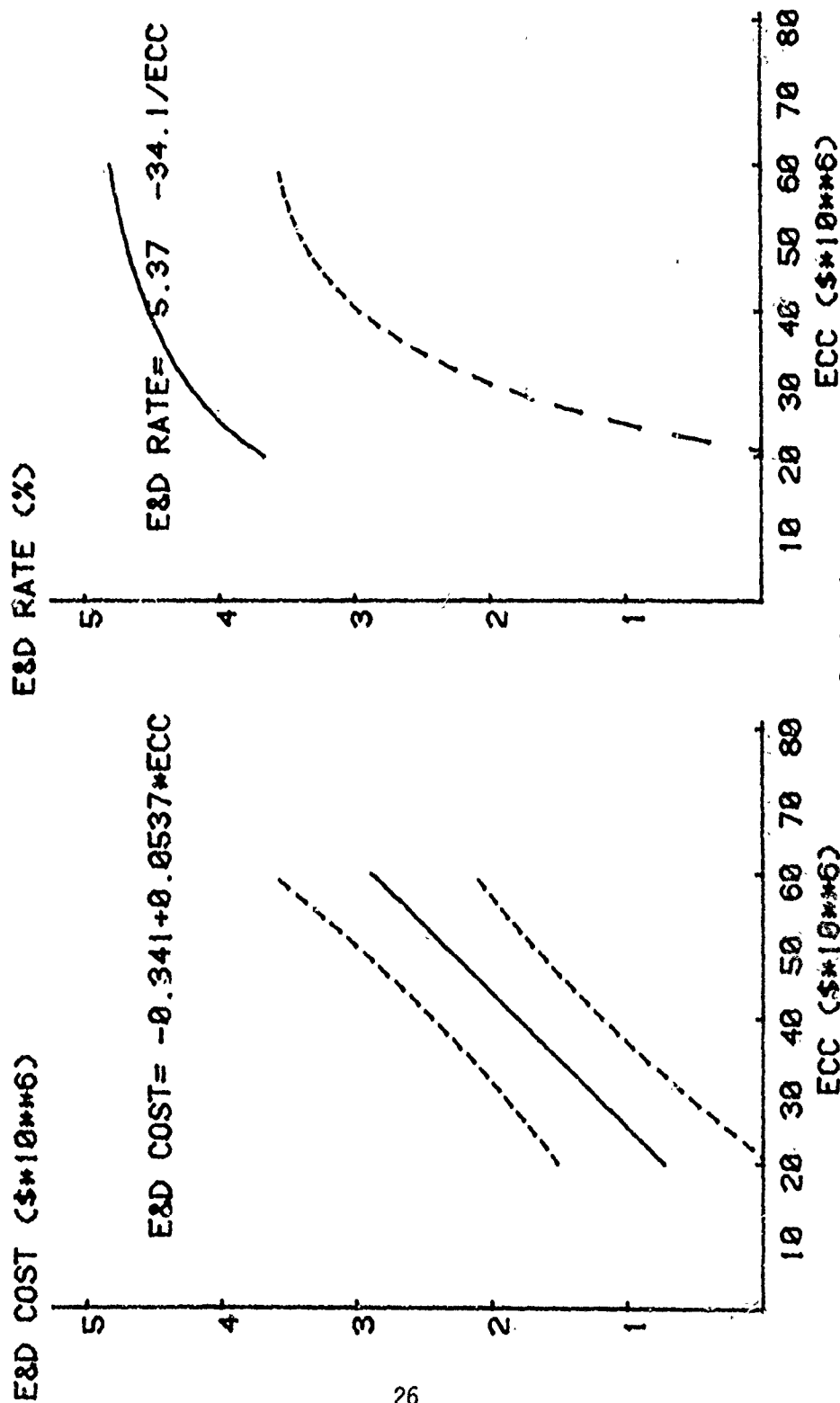--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 3.30 -6.6/ECC

E&D COST ($*10**6)

E&D COST= -0.066+0.0330*ECC

a. Contract

Figure 7. Prediction of E&D Costs/Rates - Pacific Ocean - FY78.

32

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
PACIFIC (INHOUSE) – FY78
—— PREDICTED VALUE
—-- 95% PREDICTION LIMITS

E&D COST ($*10**6)

E&D COST= -0.003 0.0000*ECC

ECC ($*10**6)

E&D RATE (%)

E&D RATE= 0.00   -0.3/ECC

ECC ($*10**6)

b. In-House

Figure 7 (con't)

33

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
PACIFIC (TOTAL) - FY78
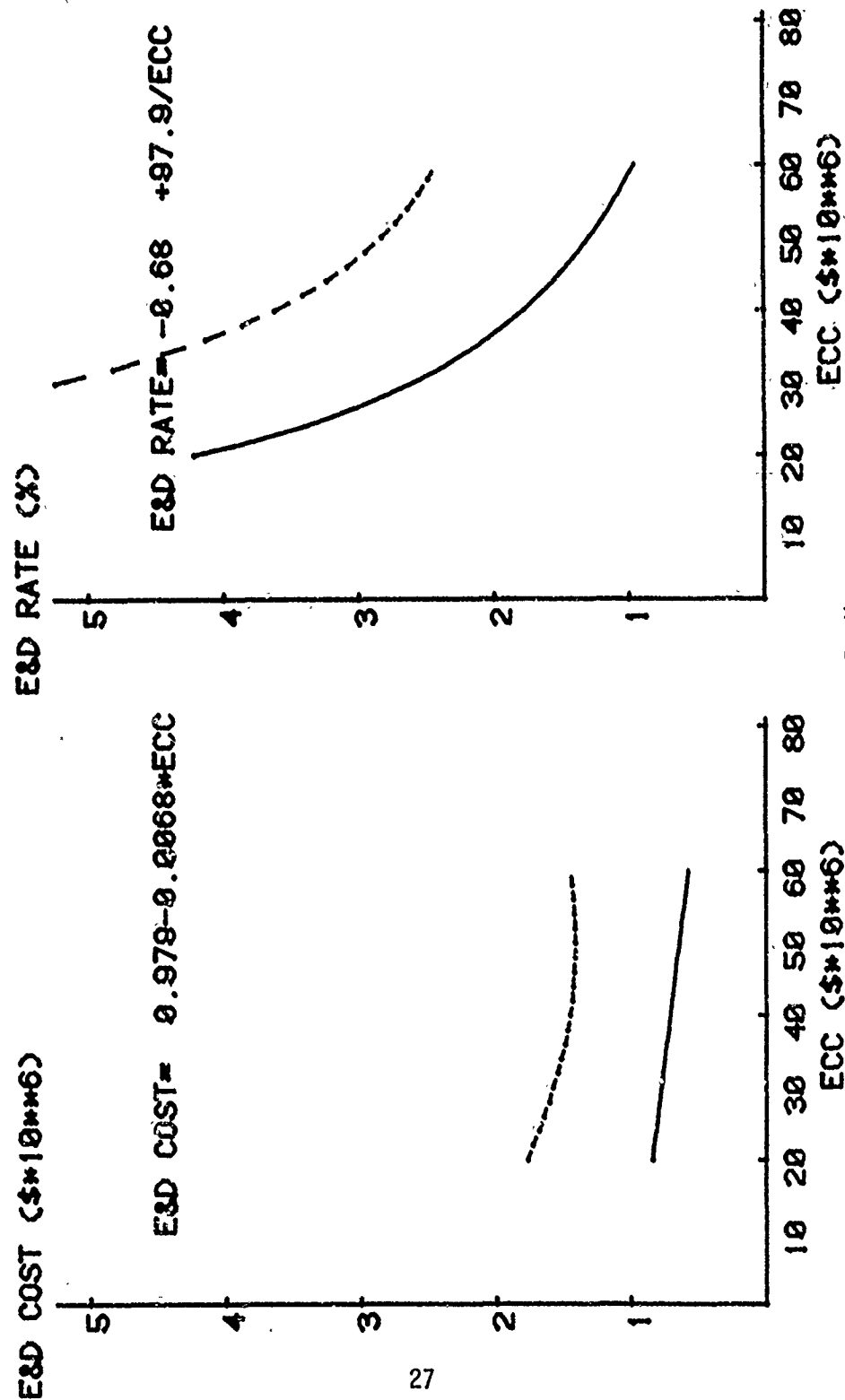
— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D COST ($*10mm6)

E&D COST= -1.263+0.0467*ECC

ECC ($*10mm6)

E&D RATE (%)

E&D RATE= 4.67 -126.3/ECC

ECC ($*10mm6)

c. Total

Figure 7 (con't)

34

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SACRAMENTO (CONTRACT)-FY 78
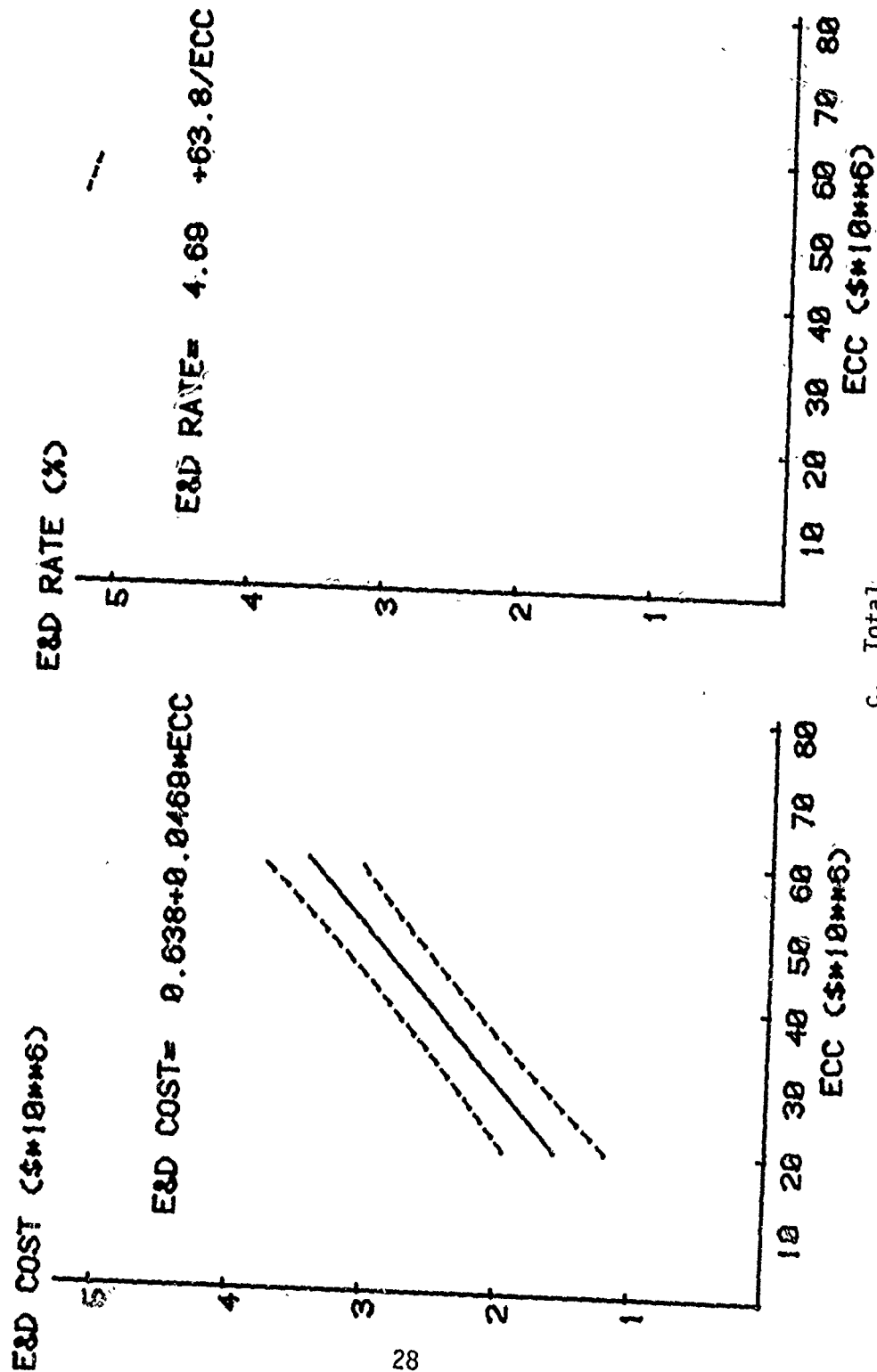—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D COST ($*10**6)

E&D COST= -0.402+0.0498*ECC

ECC ($*10**6)

E&D RATE (%)

E&D RATE= 4.98 -40.2/ECC

ECC ($*10**6)

a.   Contract

Figure 8.   Prediction of E&D Costs/Rates - Sacramento - FY78.

35

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SACRAMENTO (INHOUSE)-FY 78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

b. In-House

Figure 8 (con't)

36

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SACRAMENTO (TOTAL) - FY 78
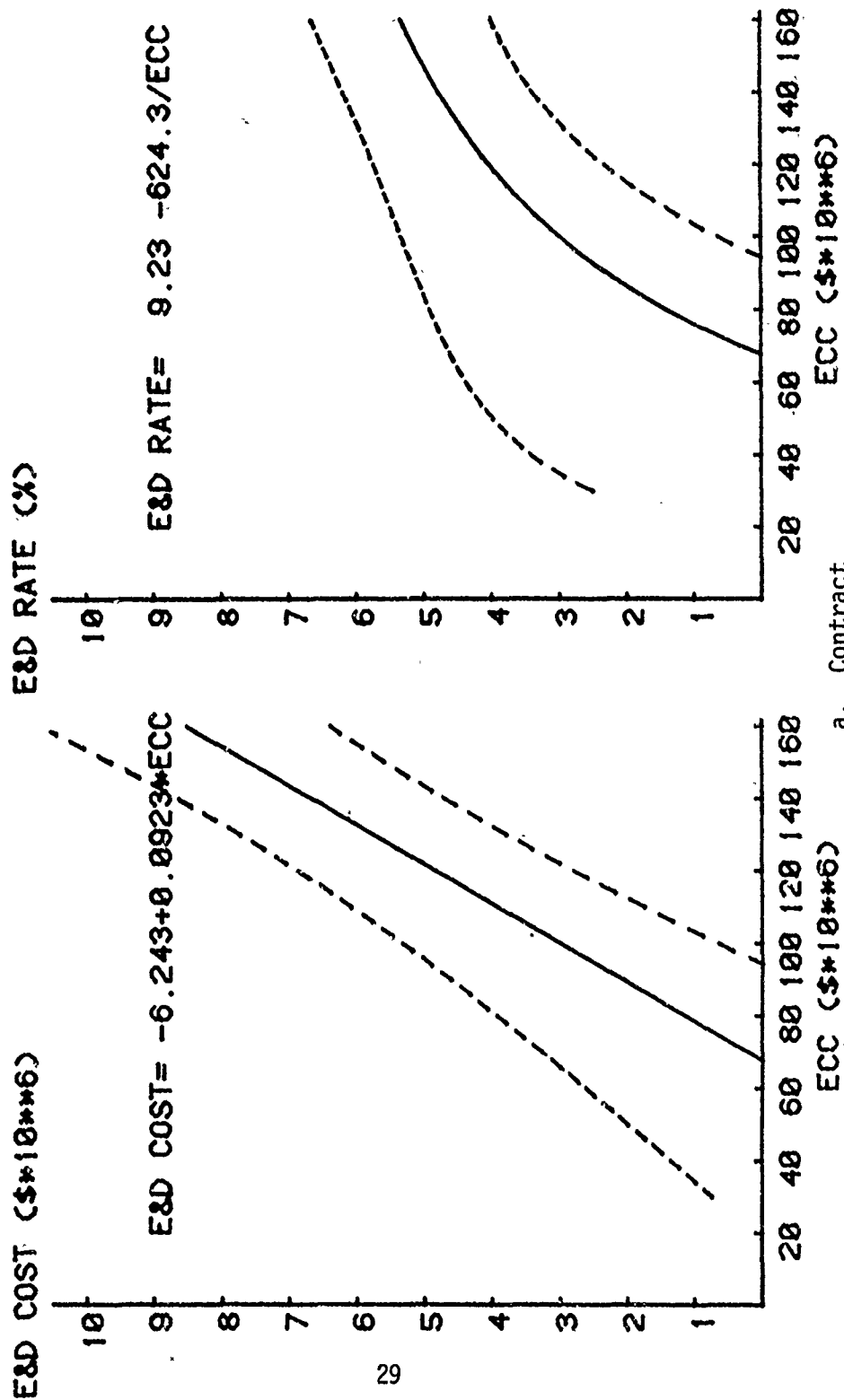—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D RATE (%)

E&D RATE= 6.79 -206.1/ECC

ECC ($*10**6)

E&D COST ($*10**6)

E&D COST= -2.061+0.0678*ECC

ECC ($*10**6)

c. Total

Figure 8 (con't)

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SAVANNAH (CONTRACT) - FY78
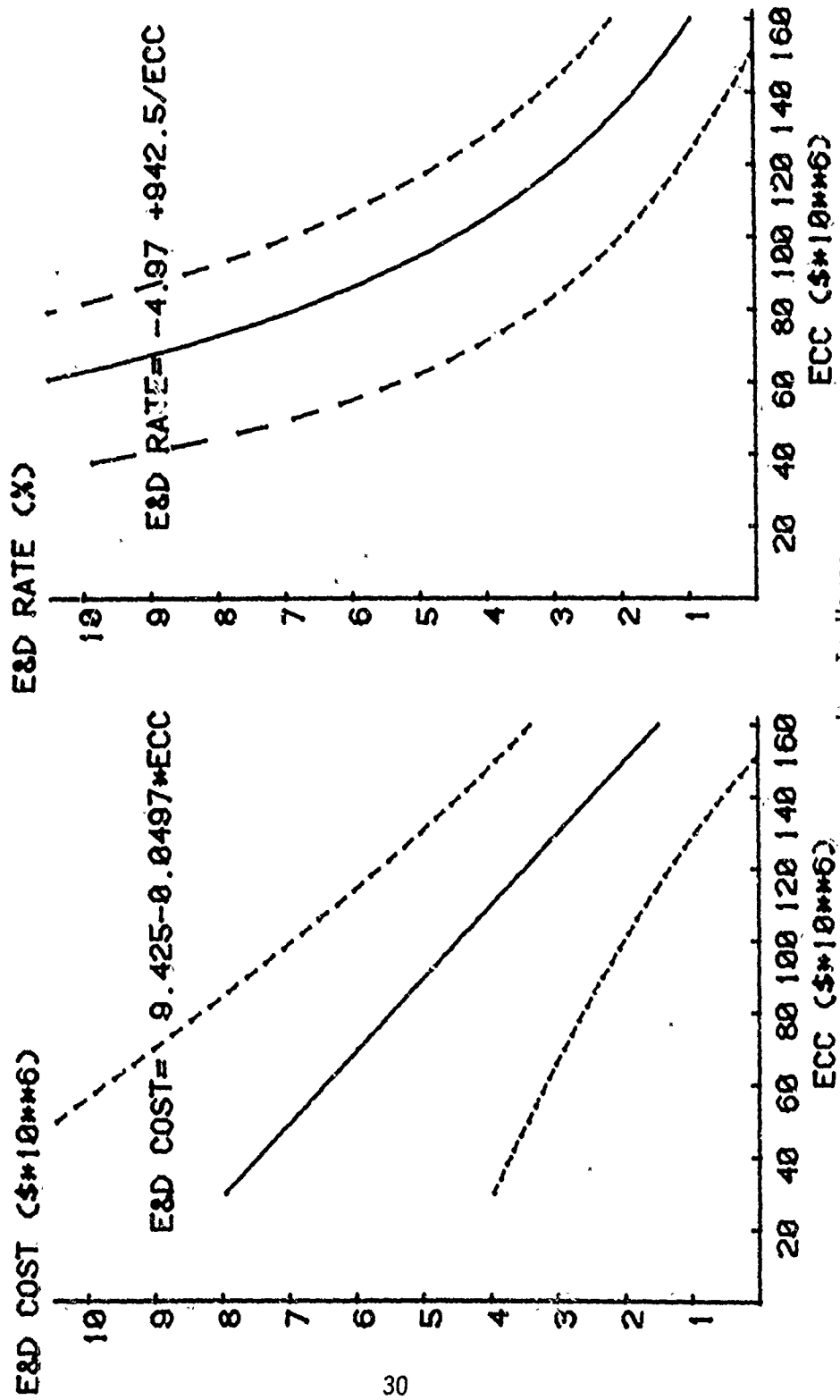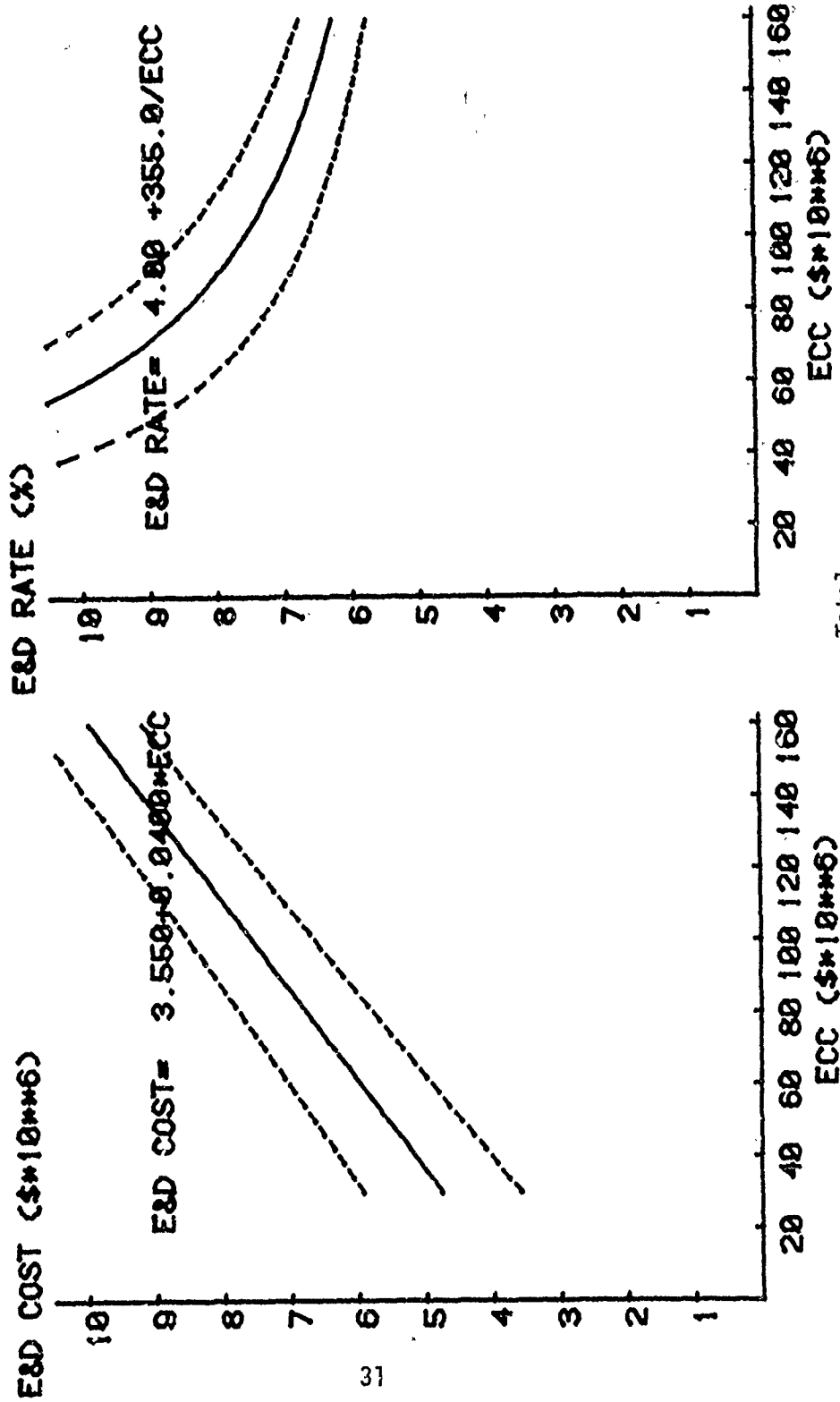—— PREDICTED VALUE
--- 95% PREDICTION LIMITS
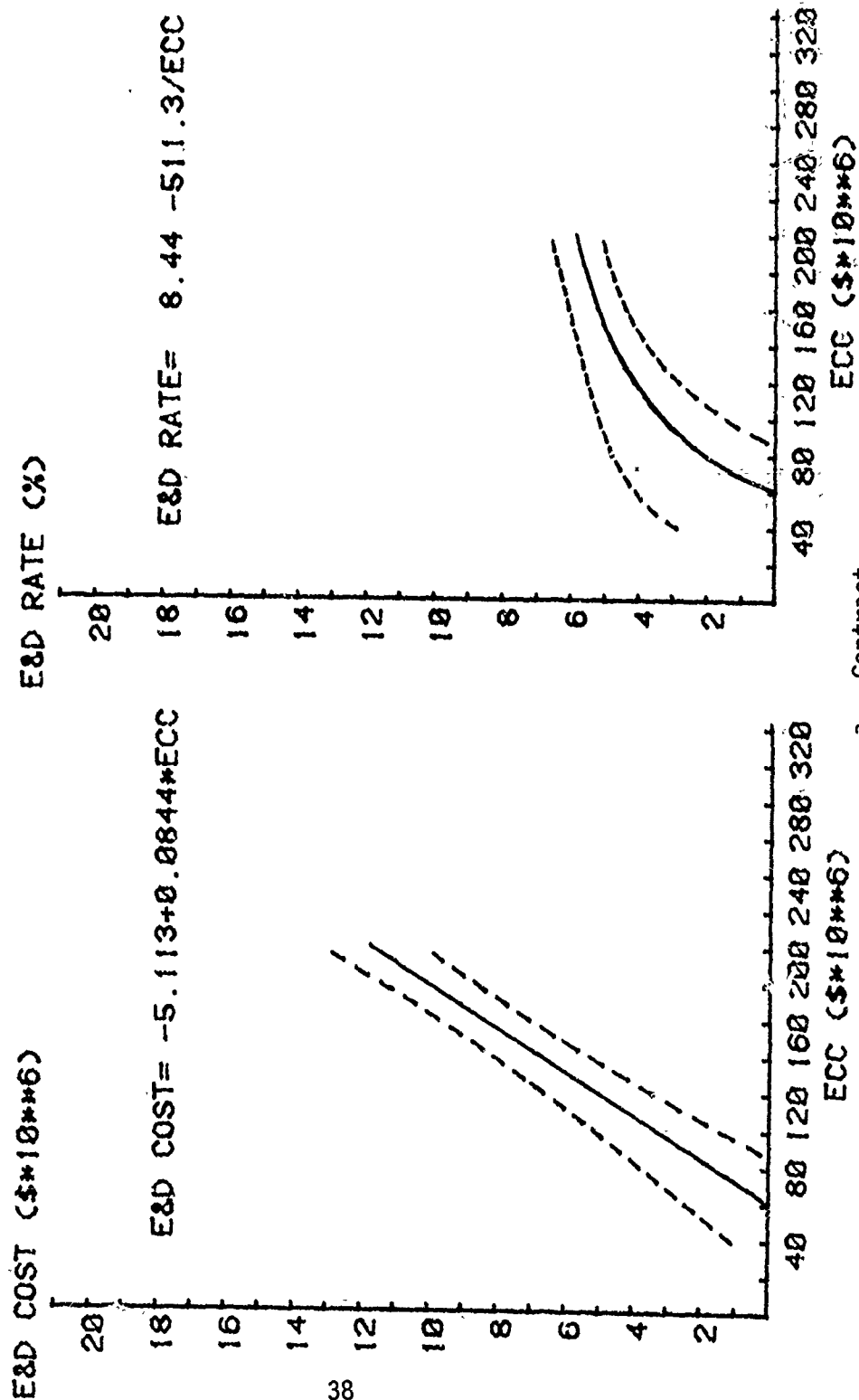
a. Contract

Figure 9. Prediction of E&D Costs/Rates - Savannah - FY78.

38

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SAVANNAH (INHOUSE) — FY78
—— PREDICTED VALUE
---- 95% PREDICTION LIMITS

E&D COST ($*10**6)

E&D COST= 1.788-0.0046*ECC

E&D RATE (%)

E&D RATE= -0.46 +178.8/ECC
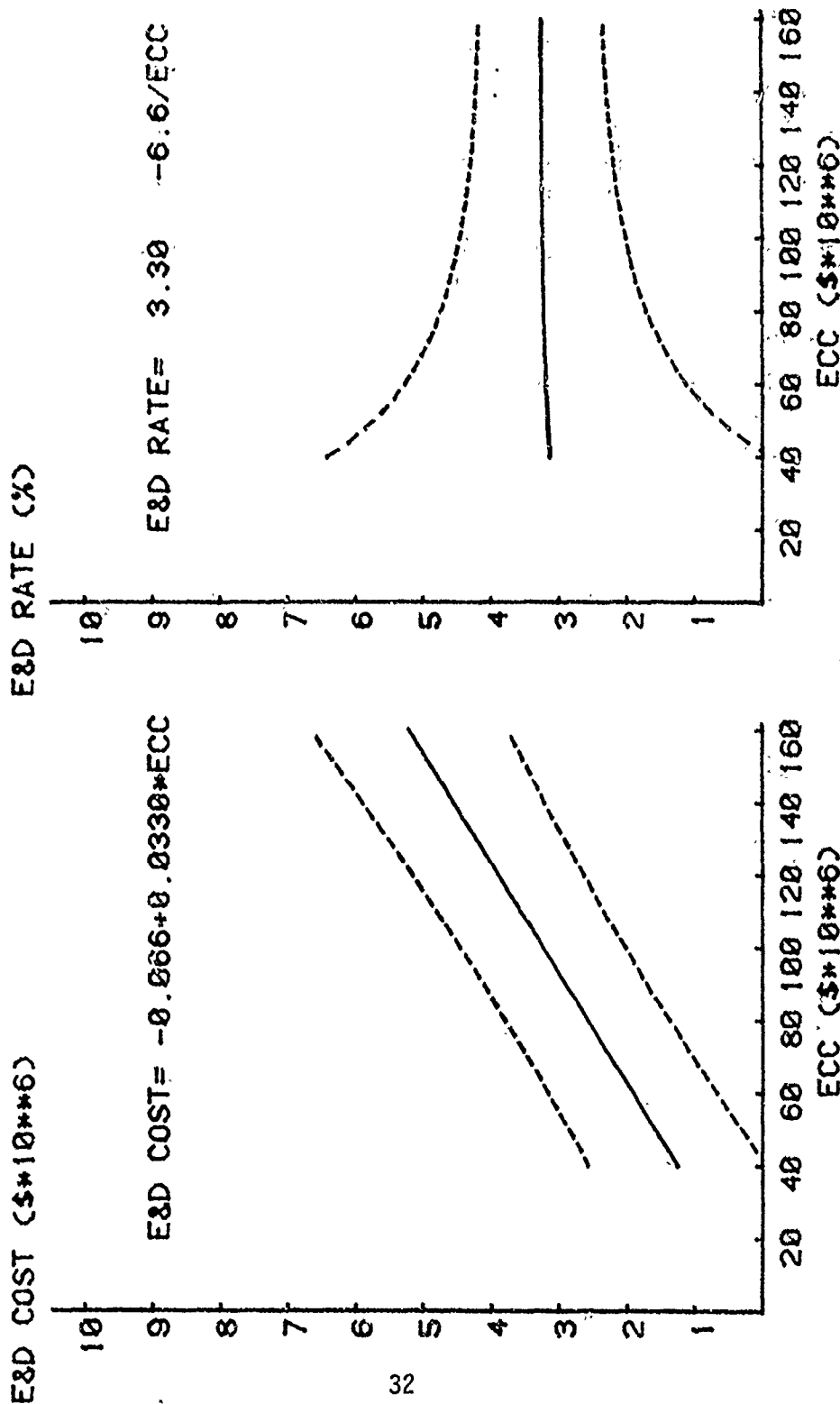
ECC ($*10**6)

ECC ($*10**6)
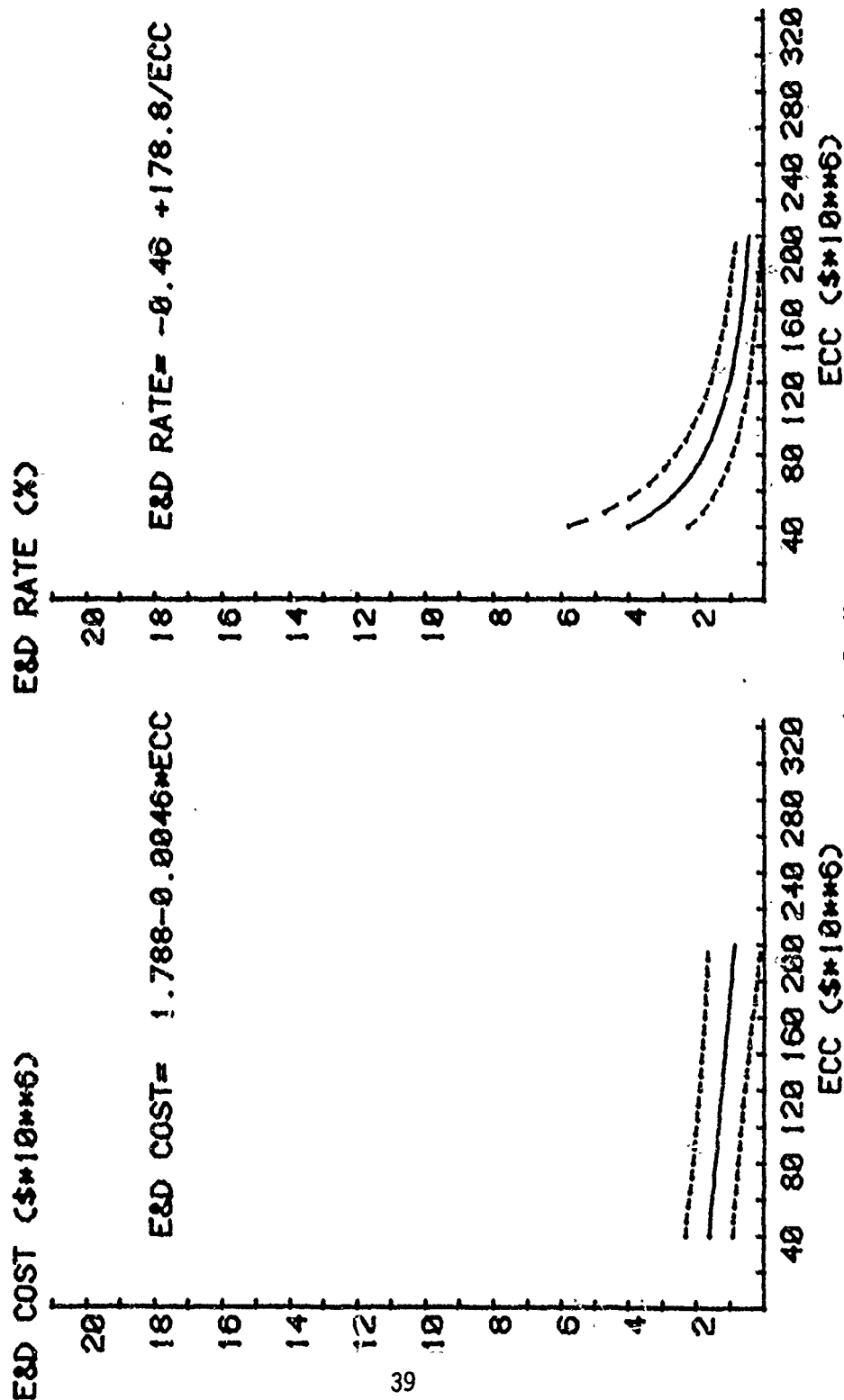
b. In-House

Figure 9 (con't)

39

E AND D COST/RATE VS ESTIMATED COST OF CONSTRUCTION
SAVANNAH (TOTAL) - FY78
—— PREDICTED VALUE
--- 95% PREDICTION LIMITS

E&D COST ($*10**6)
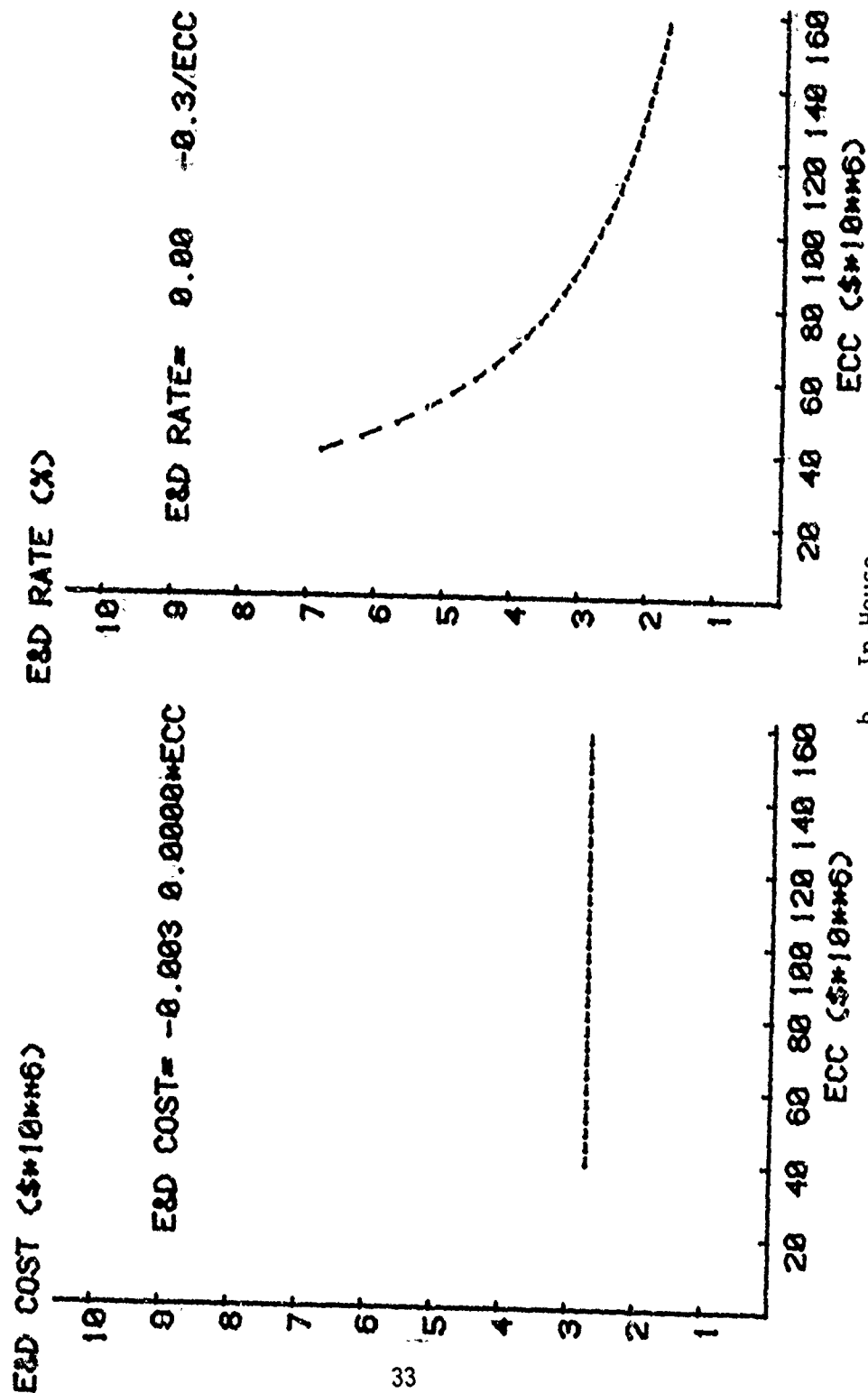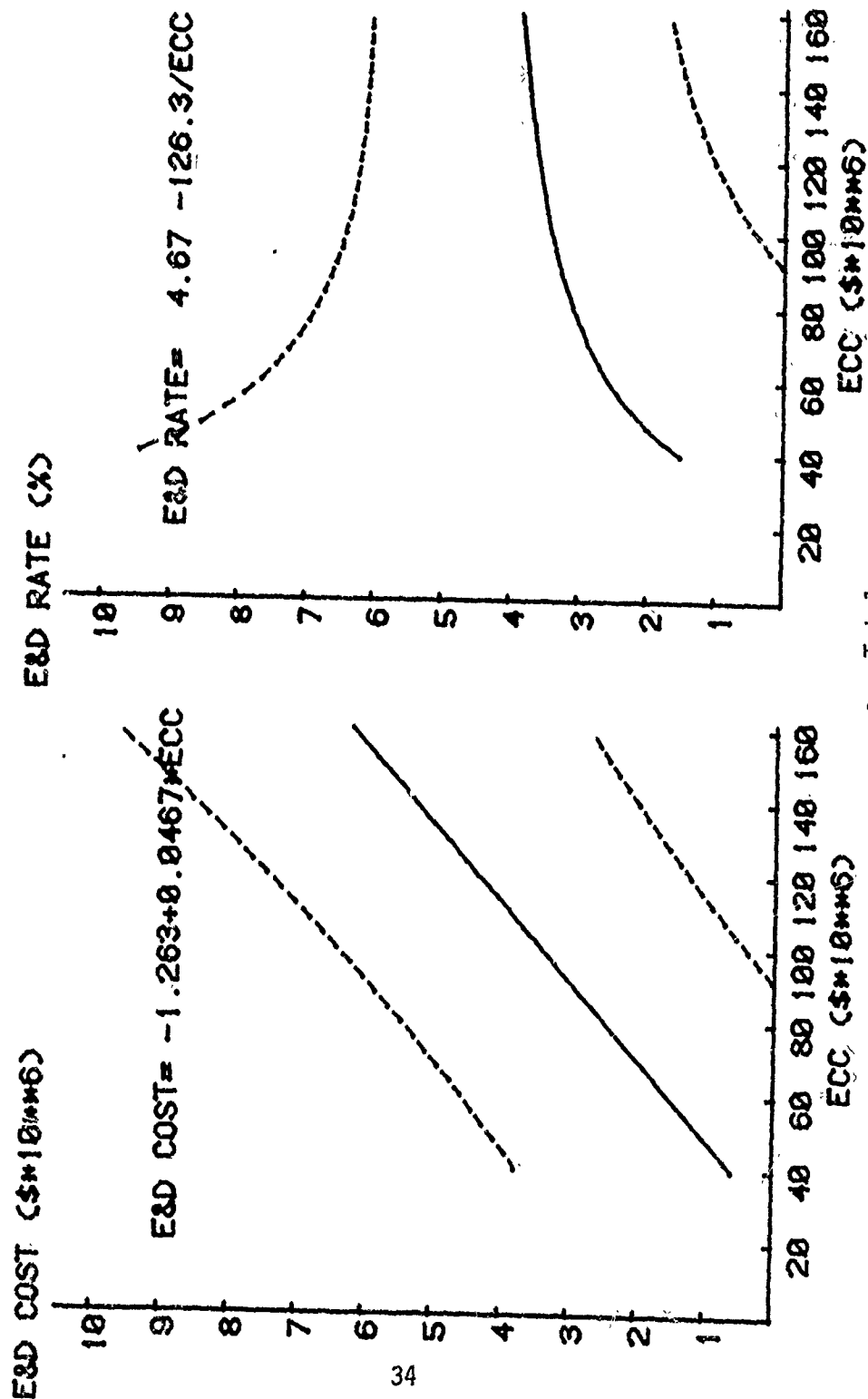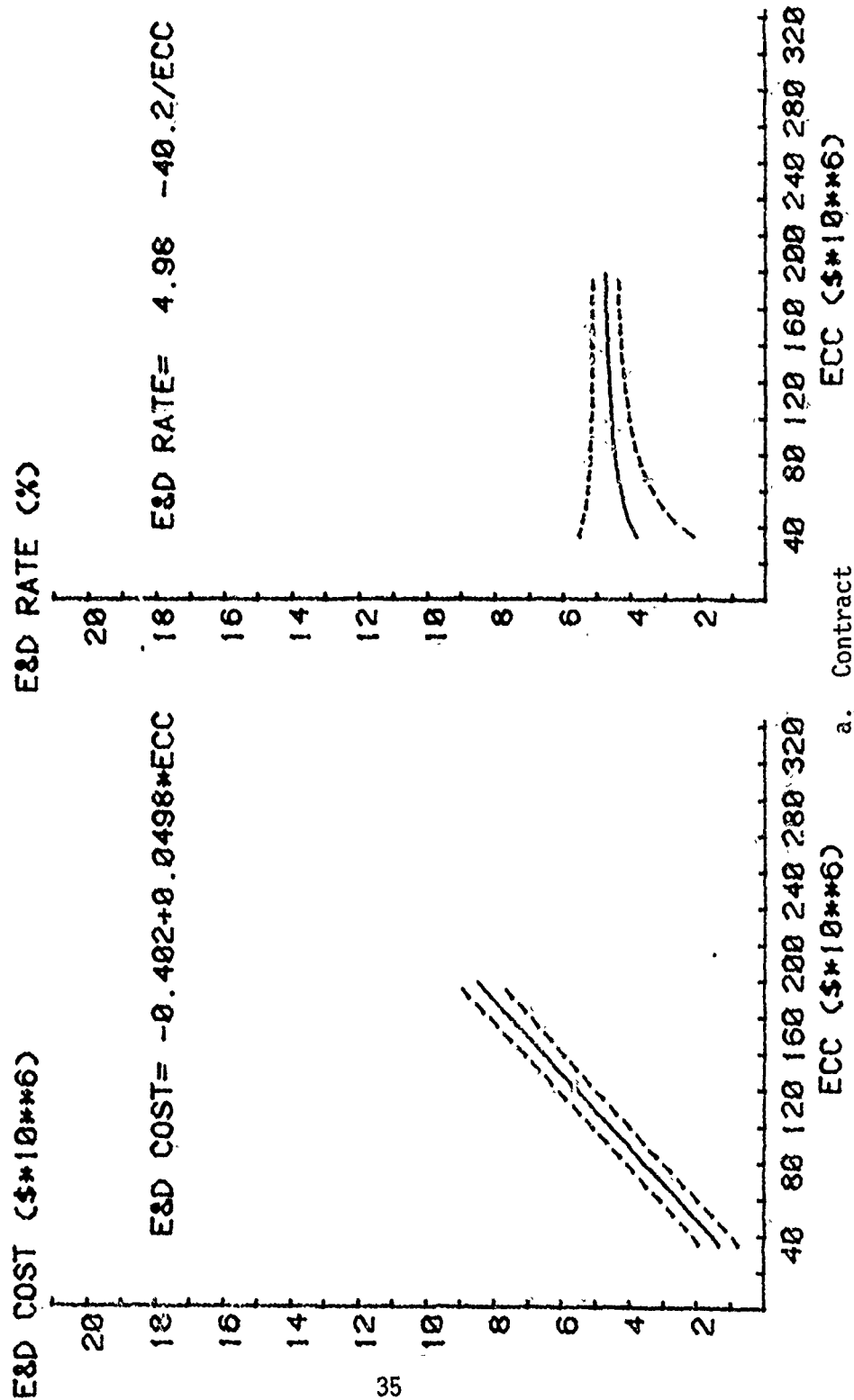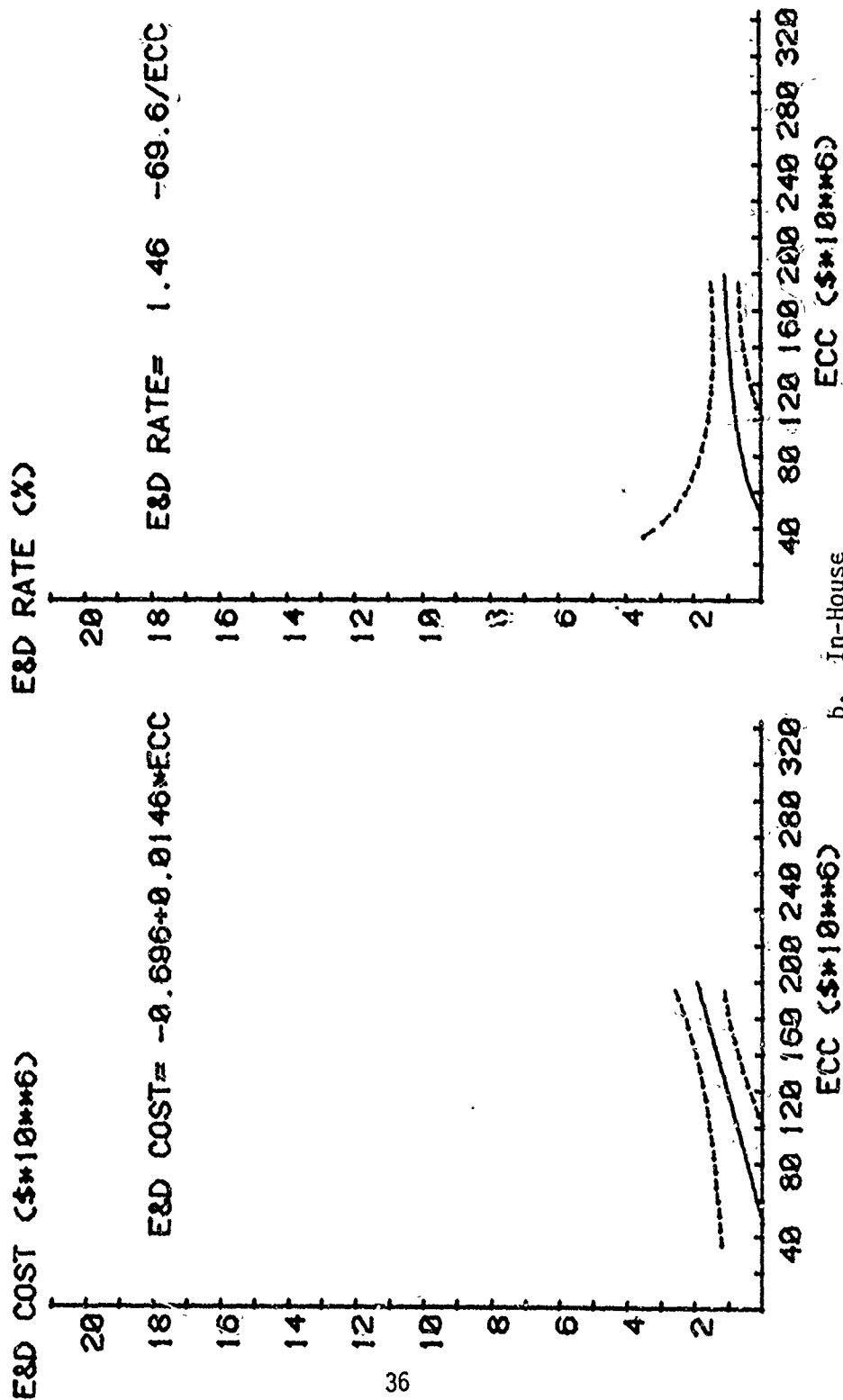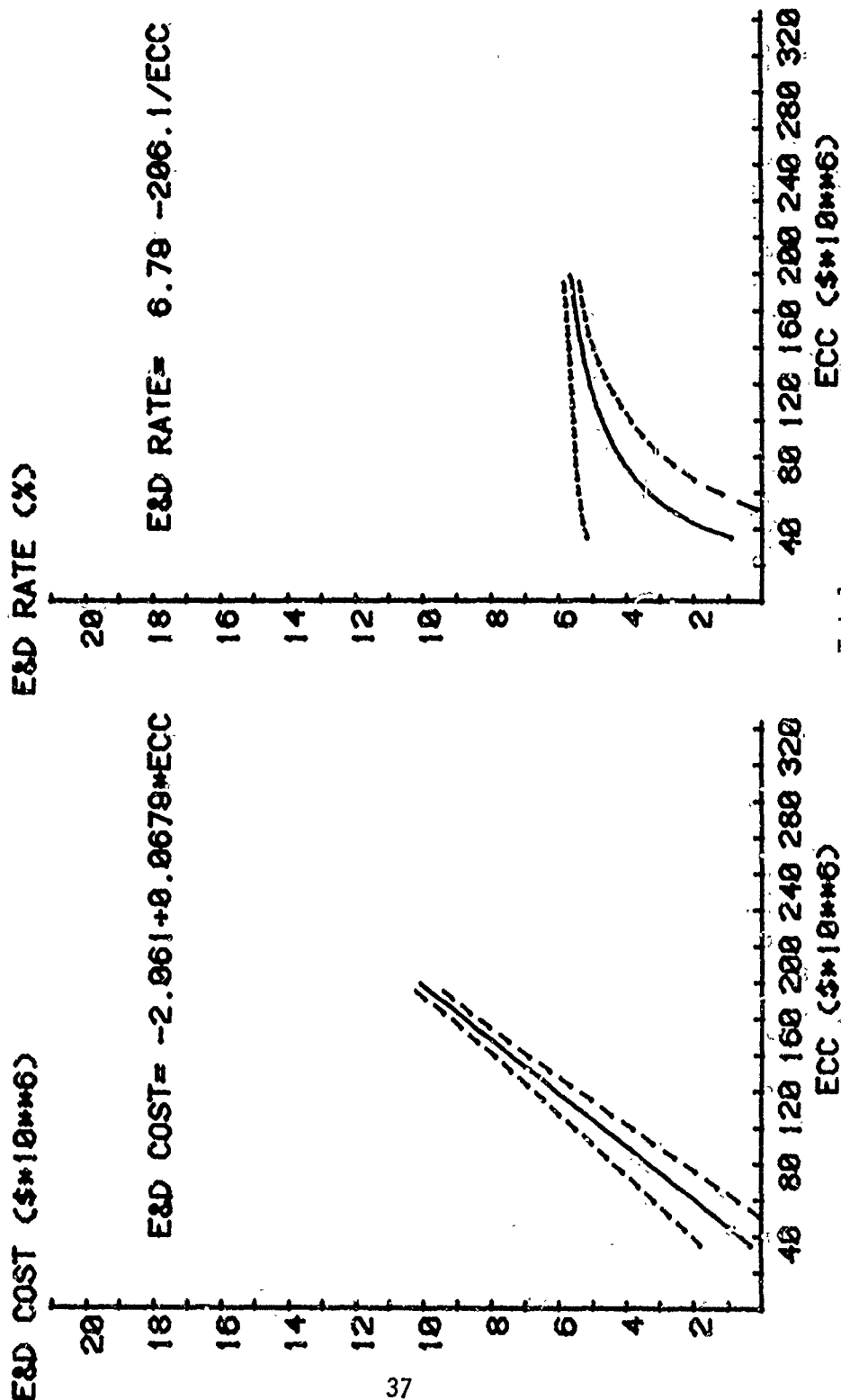
E&D COST= -2.690+0.0755*ECC

40 80 120 160 200 240 280 320
ECC ($*10**6)

E&D RATE (%)

E&D RATE= 7.55 -269.0/ECC

40 80 120 160 200 240 280 320
ECC ($*10**6)
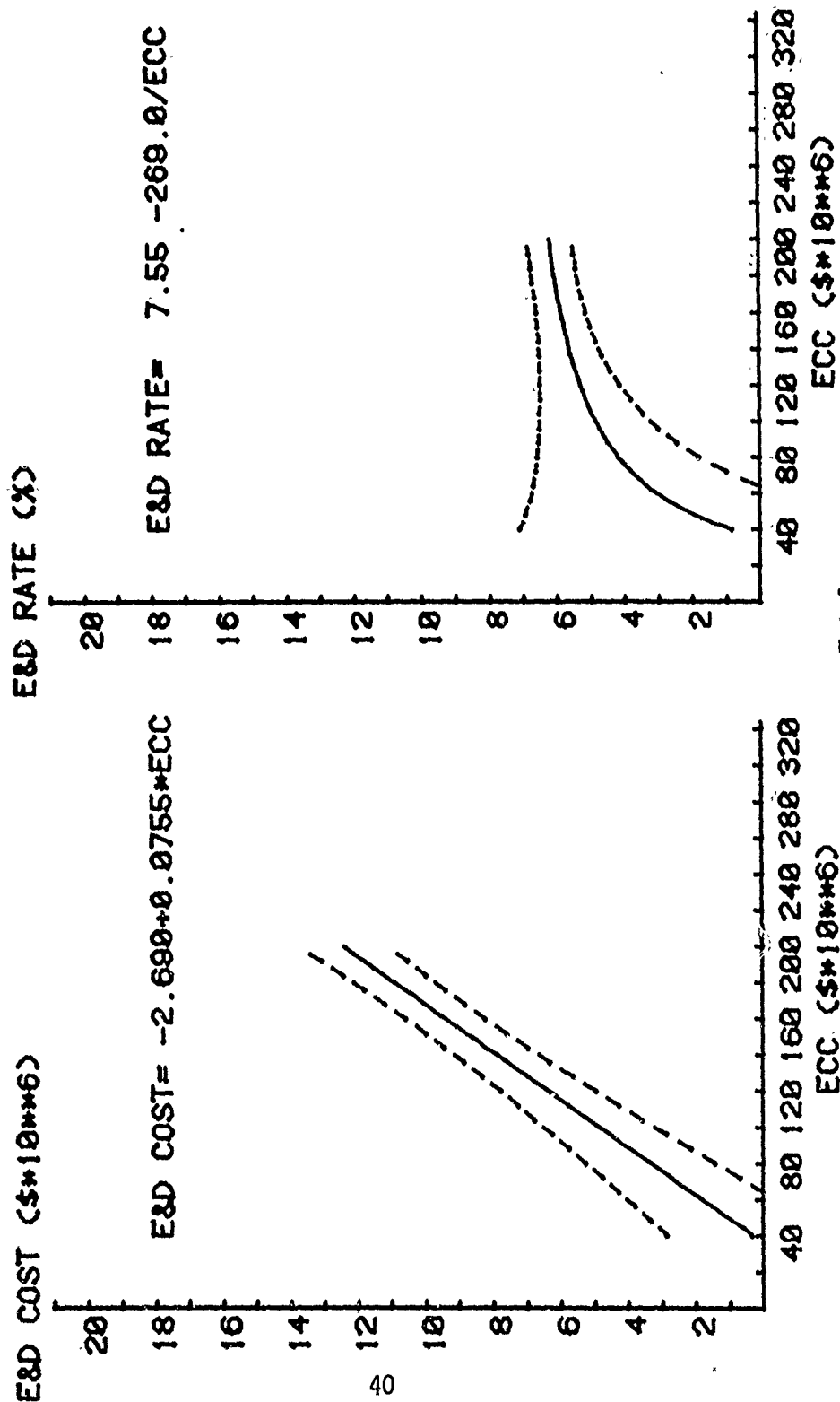
c. Total

Figure 9 (con't)

40

Table 2

FY77 Predictions Vs. Actual E&D Costs (X $1000)

Dist/Div	Contract E&D					In-House E&D				
	Actual	Predicted	Deviation and Percent	95% Limits Lower	Upper	Actual	Predicted	Deviation and Percent	95% Limits Lower	Upper
Alaska	1376	1073	303 (22%)	254	1891	1278	1866	-588 (46%)	764	2969
Baltimore	6361	5890	471 (7%)	4970	6811	1104	1451	-347 (31%)	1095	1807
Fort Worth	10532	10229	303 (3%)	6560	13897	1618	2625	-1007 (62%)	185	5065
Mobile	6694	7261	-567 (8%)	4662	9860	922	1566	-644 (70%)	169	2964
New York	2343	1749	594 (25%)	790	2708	411	988	-577 (140%)	0	2369
Omaha	4726	2779	1946 (41%)	151	5408	3087	4887	-1800 (58%)	872	8901
Pacific Ocean	4467	3077	1390 (31%)	1567	4587	1368	55	1313 (96%)	0	3437
Sacramento	8022	7504	518 (6%)	6307	8701	1727	1851	-124 (7%)	491	3211
Savannah	8510	9152	-642 (8%)	6596	11707	1212	213	999 (82%)	0	1170

Table 3

FY77 Prediction of Total E&D Costs

Dist/Div	Actual	Predicted	Deviation and Percent	95% Limits Lower	Upper
Alaska	2654	2939	-285 (11%)	2463	3414
Baltimore	7465	7341	124 (2%)	6300	8383
Fort Worth	12150	12854	-703 (6%)	10941	14767
Mobile	7616	8827	-1211 (16%)	7563	10091
New York	2754	2737	17 (1%)	2077	3397
Omaha	7813	7666	147 (2%)	5855	9478
Pacific Ocean	5835	3132	2703 (30%)	372	5892
Sacramento	9749	9355	394 (3%)	8669	10041
Savannah	9722	9364	368 (4%)	7048	9365

5 MODEL USE AND MAINTENANCE

The model can be used to predict in-house, contract, and total E&D costs/rates for a particular Division/District based on its past performance. These estimates can be used by DMC to establish targets. DMC must exercise its managerial control in using these estimates. Changes in OCE policy, in Divisions/Districts' available manpower, or in assigned workload (type and quantity) will all influence the final E&D rates. Additionally, the Division/District performance is influenced by the established target; i.e., the target may be such that major changes in management procedures or operations are required to meet it, while past data is based on prior management procedures or operations. Thus, the estimates predicted by the model should be considered as good guides for setting target rates only when they are combined with other managerial information.

6 CONCLUSIONS AND RECOMMENDATIONS

The model presented in this report is valid for predicting future E&D costs; however, caution should be used when applying the in-house predicted values.

The model is best used to project costs 1 year in advance. Thus, as soon as an additional year's data is available, the model should be updated.

It is recommended that DMC use the model to help establish E&D targets for applicable Divisions/Districts.

APPENDIX A:

DATA FOR FY69 THROUGH FY77

ALASKA DISTRICT

FY.	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	15.526	17.498	1.157	6.612	.017	1.140
1970	15.326	16.238	1.201	7.396	.043	1.158
1971	11.550	11.550	.867	7.506	.025	.842
1972	8.156	8.156	.612	7.504	.017	.595
1973	21.025	21.025	1.170	5.565	.308	.862
1974	29.340	29.340	1.681	5.729	.926	.755
1975	26.589	26.589	1.444	5.431	.807	.637
1976	32.841	32.841	2.210	6.729	.869	1.341
1977	38.552	38.552	2.654	6.890	1.376	1.278

Note: The E&D rate is based on total E&D cost.

BALTIMORE DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	33.714	35.697	2.228	6.241	1.345	.883
1970	44.262	46.865	2.654	5.663	2.051	.603
1971*	86.439	86.439	4.225	4.888	3.731	.494
1972*	133.997	133.997	6.480	4.836	5.961	.519
1973*	152.460	152.460	7.813	5.125	7.028	.785
1974	152.560	152.560	7.380	4.837	6.462	.918
1975	128.000	128.000	6.594	5.152	5.655	.939
1976	106.050	106.050	5.654	5.331	4.632	1.022
1977	138.535	138.535	7.465	5.389	6.361	1.104

*Data adjusted to reflect that no E&D was performed
 in Norfolk District.

EUROPEAN DIVISION

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	10.830	11.467	.769	6.706		
1970	12.853	18.080	1.086	8.303		
1971						
1972						
1973						
1974						
1975	137.713	137.713	11.041	8.017	4.610	4.720
1976	102.919	102.919	5.967	5.798	5.241	.726
1977	221.943	221.943	14.863	6.697	13.511	1.352

FORT WORTH DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	74.778	79.176	4.435	5.601	2.394	2.041
1970	53.133	56.258	3.969	7.055	1.300	2.669
1971	75.350	75.350	4.896	6.498	2.067	2.829
1972	104.900	104.900	6.128	5.842	4.094	2.034
1973	122.985	122.985	6.921	5.628	5.551	1.370
1974	145.416	145.416	8.055	5.539	6.532	1.523
1975	204.842	204.842	10.141	4.951	8.183	1.958
1976	288.839	288.839	14.892	5.156	13.389	1.503
1977	230.684	230.684	12.150	5.267	10.532	1.618

HUNTSVILLE DIVISION

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1970	204.532	216.563	8.184	3.779	5.041	3.143
1971	241.000	241.000	9.733	4.055	6.264	3.469
1972	216.700	216.700	9.369	4.323	8.134	1.235
1973	91.836	91.836	4.875	5.308	4.140	.735
1974	48.527	48.527	2.426	4.999	1.340	1.086
1975	180.712	180.712	11.041	6.110	5.592	5.449
1976	97.282	97.282	5.301	5.449	4.583	.718
1977	95.335	95.335	6.607	6.930	4.453	2.154

KANSAS CITY DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	50.116	53.064	2.169	4.088	1.663	.506
1970	20.920	22.151	1.276	5.761	.976	.300
1971						
1972						
1973						
1974						
1975	5.843	5.843	.315	5.391	.210	.105
1976	37.339	37.339	2.447	6.553	1.777	.670
1977	50.891	50.891	3.439	6.758	2.343	1.096

LOS ANGELES DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	57.364	60.738	4.039	6.650	2.430	1.609
1970	33.373	35.336	2.336	6.611	1.383	.953
1971	3.257	3.257	.318	9.764	.280	.038
1972	.658	.658	.110	16.717	.088	.022

MEDITERRANEAN DIVISION

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	36.544	35.694	1.248	3.225	.453	.795
1970	20.820	22.045	.907	4.114	.271	.636
1971	13.844	18.844	.988	7.187	.431	.555
1972	27.445	27.445	1.871	6.817	1.204	.667
1973	20.695	20.695	1.646	7.954	.931	.715
1974	96.356	96.356	3.165	3.285	-	-
1975	1259.372	1259.372	9.505	.755	8.614	.891
1976	1890.213	1890.213	14.558	.770	13.824	.734
1977	4516.357	4516.357	63.229	1.400	62.871	.358

MOBILE DISTRICT

FY	ECC (\$ Mil)	Adj ECC (\$ Mil)	E&D Cost (\$ Mil)	E&D Rate (%)	Contract E&D Cost (\$ Mil)	In-House E&D Cost (\$ Mil)
1969	30.889	32.706	1.821	5.568	.374	1.447
1970	63.821	67.575	2.976	4.404	1.429	1.547
1971	71.261	71.261	3.162	4.437	1.120	2.042
1972	95.799	95.799	4.241	4.427	2.293	1.948
1973	79.929	79.929	5.087	6.364	3.450	1.637
1974	129.964	129.964	6.591	5.071	5.131	1.460
1975	146.148	146.148	7.495	5.128	5.690	1.805
1976	151.946	151.946	8.520	5.607	6.884	1.636
1977	124.984	124.984	7.616	6.094	6.694	.922

NEW YORK DISTRICT

FY	ECC (\$ Mil)	Adj ECC (\$ Mil)	E&D Cost (\$ Mil)	E&D Rate (%)	Contract E&D Cost (\$ Mil)	In-House E&D Cost (\$ Mil)
1969	33.334	35.295	2.259	6.400	1.746	.513
1970	30.393	32.181	2.382	7.402	1.349	1.033
1971	27.104	27.104	1.735	6.401	1.129	.606
1972	44.376	44.376	2.638	5.945	2.190	.448
1973	60.947	60.947	3.470	5.693	2.968	.502
1974	43.805	43.805	2.735	6.244	1.698	1.037
1975	42.084	42.084	2.618	6.221	1.530	1.088
1976	42.873	42.873	2.633	6.141	2.000	.633
1977	44.089	44.089	2.754	6.246	2.343	.411

NORFOLK DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	28.139	29.794	1.993	6.689	1.308	.685
1970	29.068	30.778	2.306	7.492	1.807	.499
1971						
1972						
1973						
1974	69.945	69.945	2.730	3.903	2.501	.229
1975	76.553	76.553	3.522	4.601	2.956	.566
1976	93.510	93.510	4.982	5.328	4.460	.522
1977	61.574	61.574	3.465	5.627	2.427	1.038

OMAHA DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	28.311	29.976	2.075	6.922	.942	1.133
1970	72.893	77.181	4.211	5.456	1.870	2.341
1971*	85.574	85.574	4.796	5.605	2.469	2.327
1972*	130.335	130.335	6.752	5.180	5.374	1.378
1973*	190.712	190.712	9.605	5.036	9.464	.141
1974*	194.781	194.781	10.403	5.341	10.215	.188
1975*	172.647	172.647	9.144	5.296	8.925	.219
1976	162.186	162.186	9.698	5.980	7.451	2.247
1977	115.070	115.070	7.813	6.790	4.726	3.087

*Data adjusted to reflect that no E&D was performed at
Kansas City District for FY71-75.

PACIFIC OCEAN DIVISION

FY	ECC (\$ Mil)	Adj ECC (\$ Mil)	E&D Cost (\$ Mil)	E&D Rate (%)	Contract E&D Cost (\$ Mil)	In-House E&D Cost (\$ Mil)
1969	135.920	143.915	9.132	6.345	4.795	4.337
1970	73.209	77.515	6.490	8.373	2.451	4.039
1971	66.213	66.213	3.871	5.846	1.901	1.970
1972	74.332	74.332	3.970	5.341	2.564	1.406
1973	40.445	40.445	2.743	6.782	1.789	.954
1974	56.003	56.003	2.527	4.512	1.703	.824
1975	133.867	133.867	4.844	3.619	3.885	.959
1976	66.591	66.591	2.684	4.031	1.435	1.249
1977	116.845	116.845	5.835	4.994	4.467	1.368

SACRAMENTO DISTRICT

FY	ECC (\$ Mil)	Adj ECC (\$ Mil)	E&D Cost (\$ Mil)	E&D Rate (%)	Contract E&D Cost (\$ Mil)	In-House E&D Cost (\$ Mil)
1969	33.090	35.036	2.248	6.416	1.071	1.177
1970	34.985	37.043	2.453	6.622	1.445	1.008
1971	71.446	71.446	4.596	6.433	3.248	1.348
1972	68.049	68.049	4.035	5.930	3.153	.882
1973	81.456	81.456	4.643	5.700	3.819	.824
1974	90.403	90.403	5.068	5.606	4.003	1.065
1975	120.013	120.013	6.721	5.600	5.829	.892
1976	134.263	134.263	7.444	5.544	5.965	1.479
1977	169.715	169.715	9.749	5.744	8.022	1.727

51

SAVANNAH DISTRICT

FY	ECC ($ Mil)	Adj ECC ($ Mil)	E&D Cost ($ Mil)	E&D Rate (%)	Contract E&D Cost ($ Mil)	In-House E&D Cost ($ Mil)
1969	58.247	61.673	3.005	4.872	1.593	1.412
1970	59.922	63.447	3.489	5.499	2.086	1.403
1971	41.497	41.497	2.201	5.304	.676	1.525
1972	66.512	66.512	3.295	4.954	1.666	1.629
1973	67.684	67.684	3.204	4.734	1.693	1.511
1974	105.320	105.320	3.970	3.769	2.487	1.483
1975	169.654	169.654	8.266	4.872	7.050	1.216
1976	168.141	168.141	8.565	5.094	8.090	.475
1977	172.643	172.643	9.723	5.632	8.510	1.212

APPENDIX B:

MODEL DEVELOPMENT AND DATA ADJUSTMENTS

Model Development

In CERL Report P-77, O'Connor developed the model (Eq 1) used in this report to estimate in-house and contract E&D costs from the yearly ECC for a Division/District. Visual inspection of graphs of the data (E&D costs) plotted against time (Figures B1 through B9) indicated that the inclusion of a quadratic term in time, T^2, might improve the predictive ability of the model for AEED costs for Alaska, Baltimore, Fort Worth, Omaha, and Savannah Districts. However, regression analyses showed no significant improvement in the fit of data when the quadratic term was used.

The possibility of grouping Districts with homogeneous residual variances was not explored in depth because it is difficult to update data files for such groups. Each time an additional year's data is added to the data file, the groupings must be checked. This would involve statistical comparisons of Divisions and Districts, and the TEKTRONIX System is not adaptable to this type of analysis. Instead, a specific set of coefficients was computed for the model for each Division/District.

Data Adjustments

Prior to FY71, the ECC was defined as 85 percent of the programmed cost or, if the programmed cost was nct established, the equivalent cost. In FY71, this percentage was changed to 90 percent. The FY69 and FY70 data were adjusted accordingly by multiplying by .9/.85.

Baltimore and Omaha data required special adjustments, because Baltimore performed E&D for Norfolk in FY71 through FY73, while Omaha did likewise for Kansas City in FY71 through FY74. Linear regressions were used to fit lines to the Norfolk and Kansas City data. These provided estimates of INHED, AEED, and ECC for the missing years (see Figures B10 and B11). These estimated values were then subtracted from the corresponding year's values for Baltimore and Omaha. These adjusted values, which are given in Appendix A and in Figures B2 and B6, were used to develop the prediction models for Baltimore and Omaha.

53
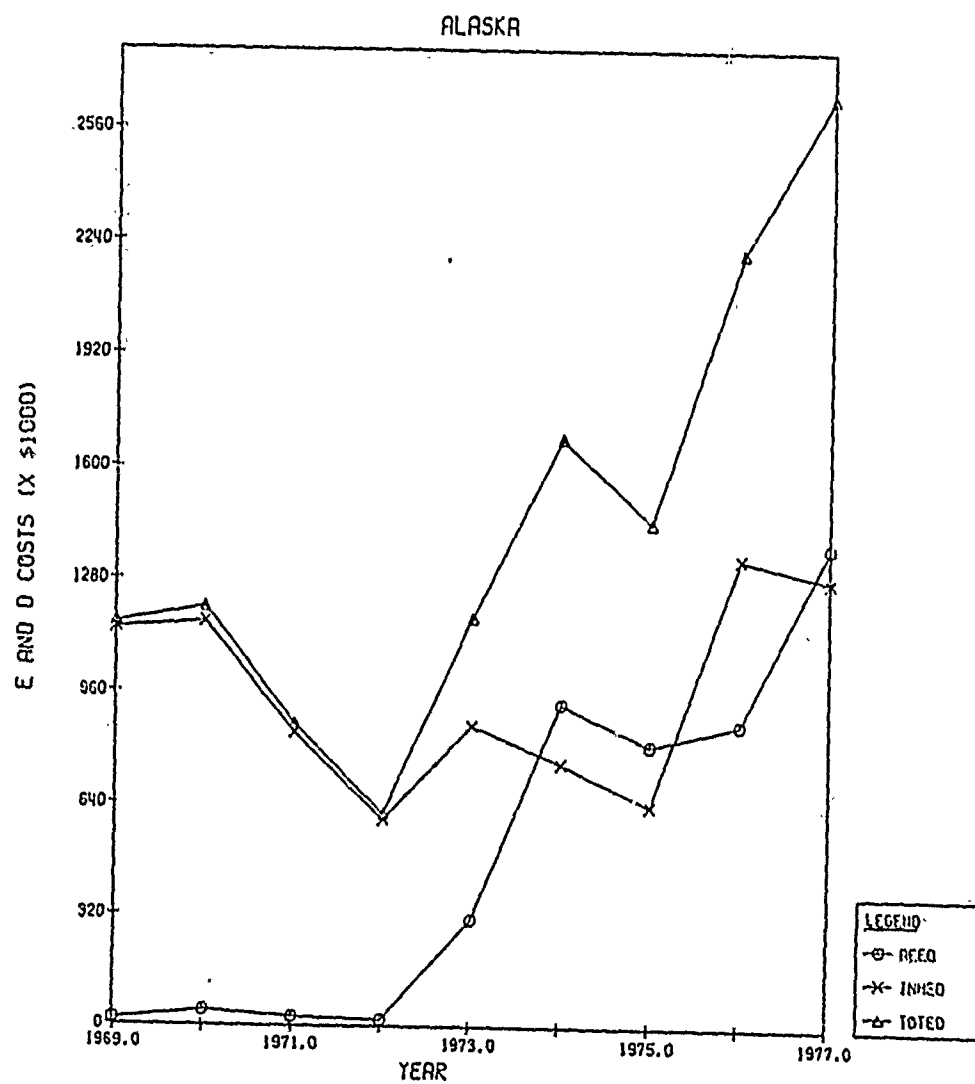
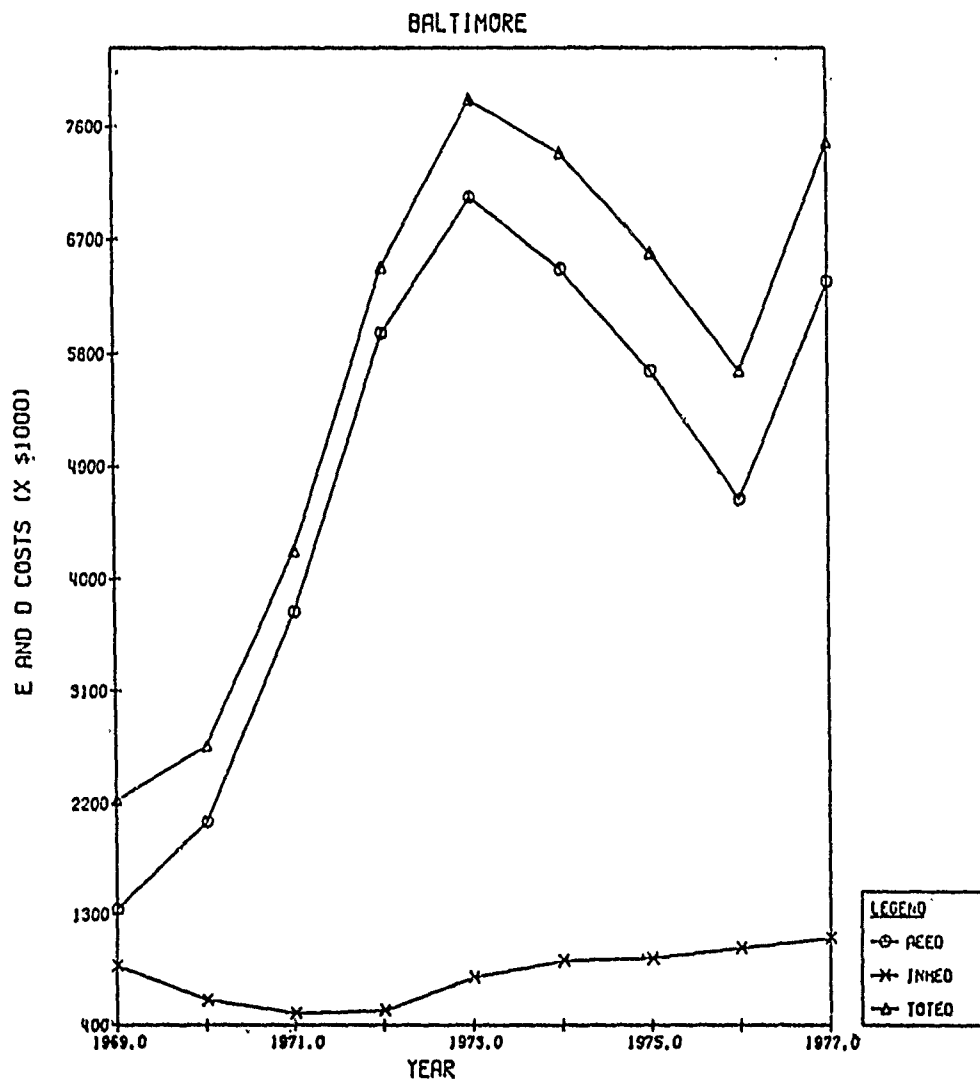Figure B1.   E&D costs vs years - Alaska.
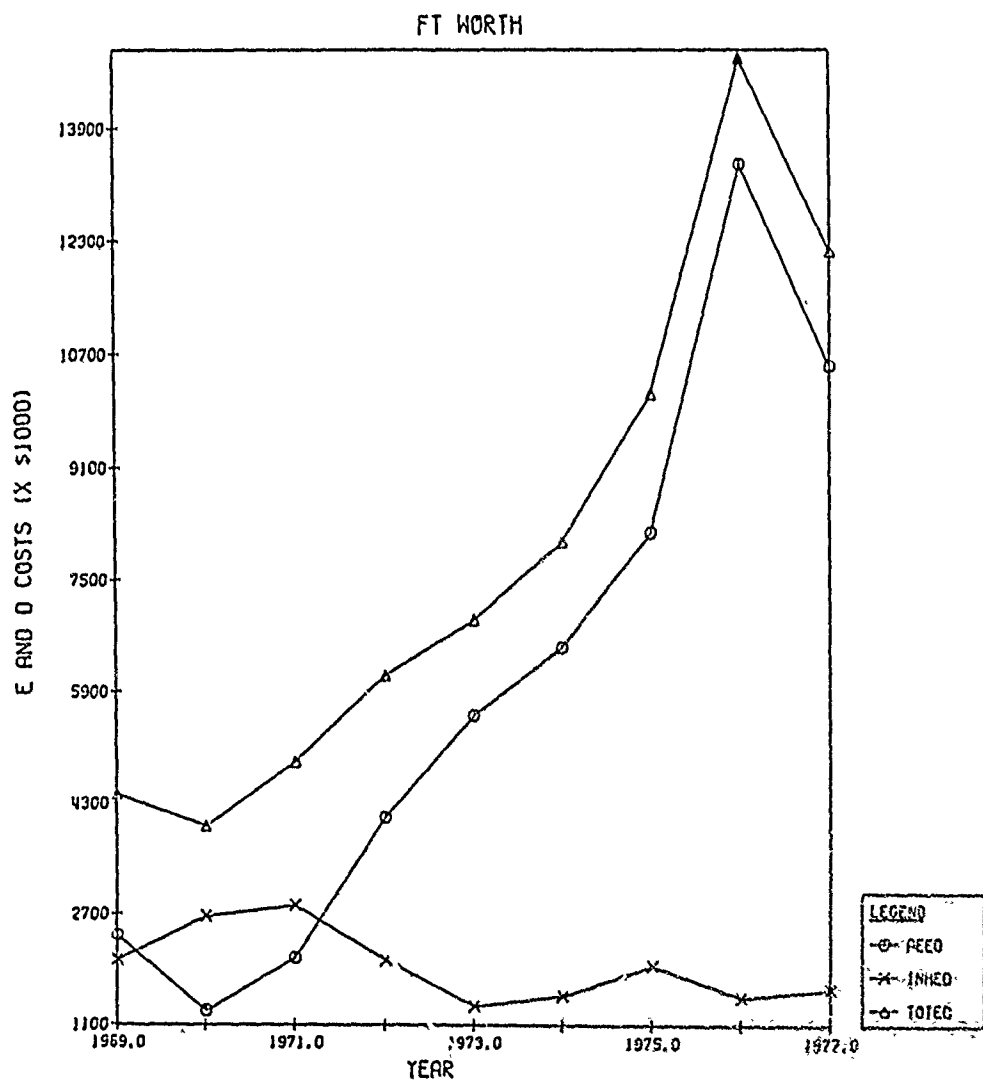
54

Figure B2. E&D costs vs years - Baltimore.

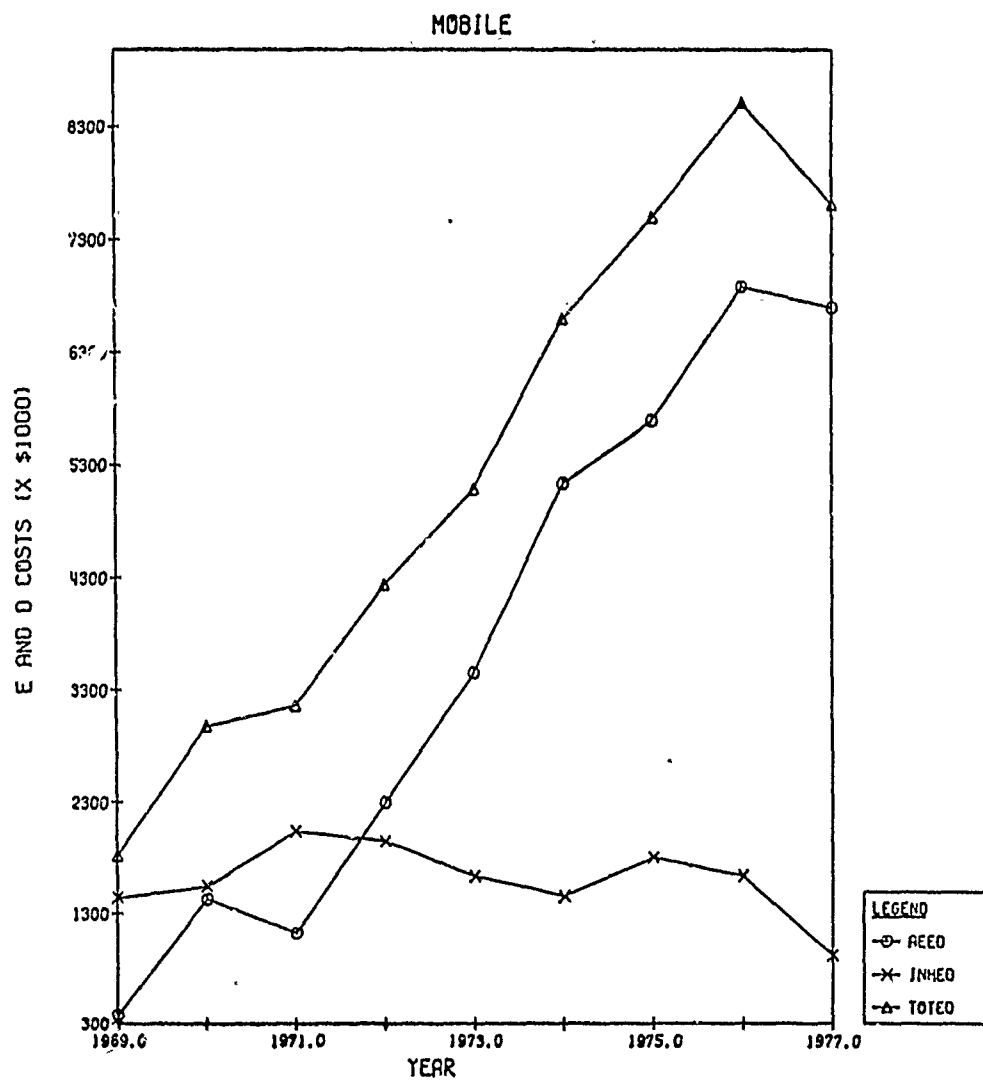Figure B3. E&D costs vs years - Fort Worth.
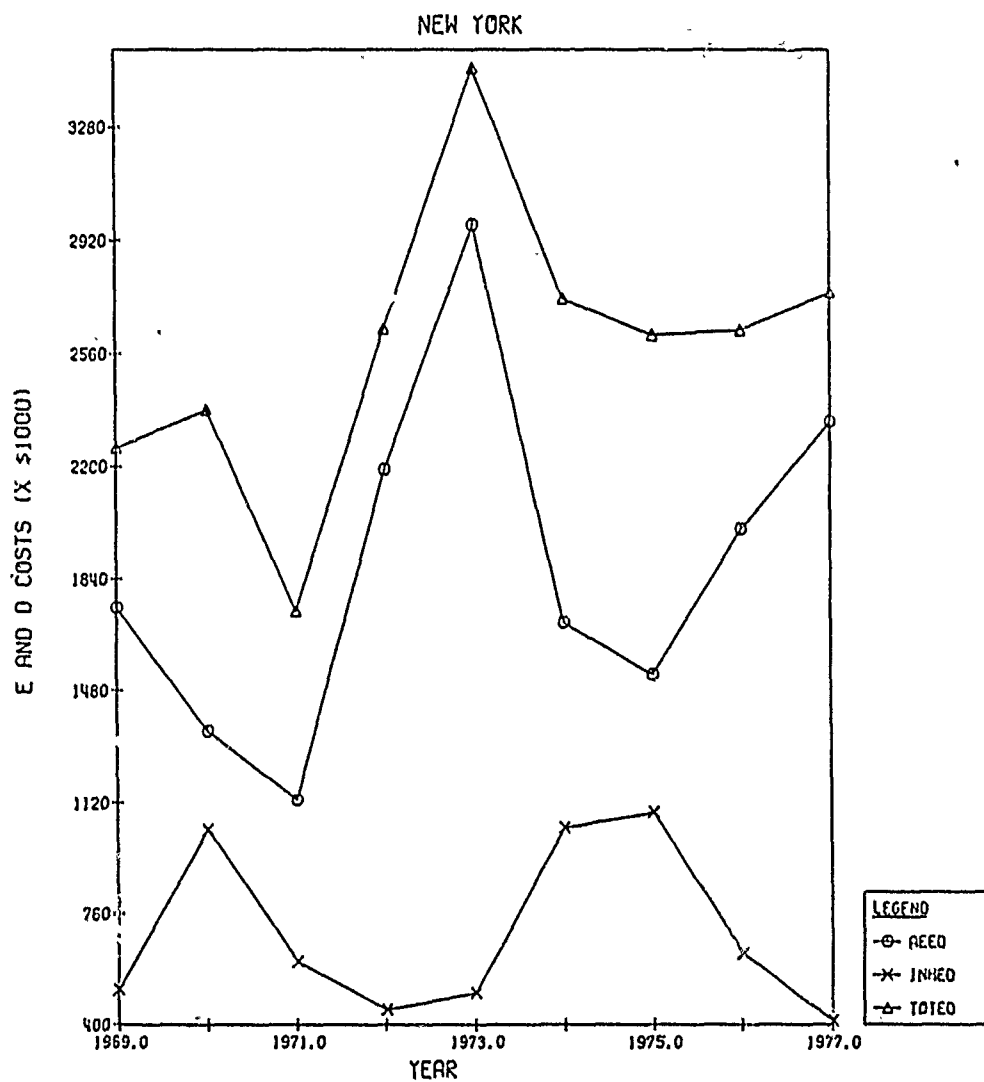
Figure B4.   E&D costs vs years - Mobile.

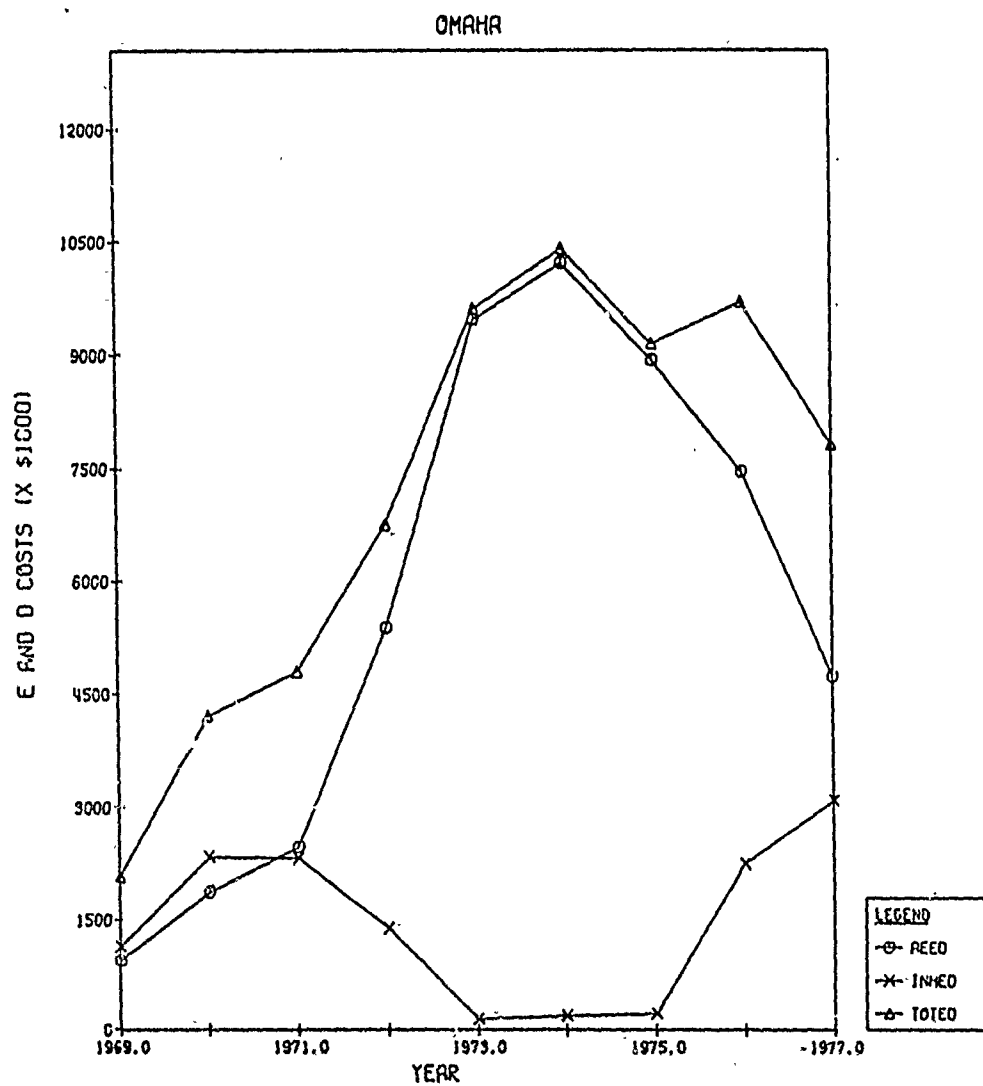Figure B5. E&D costs vs years - New York.
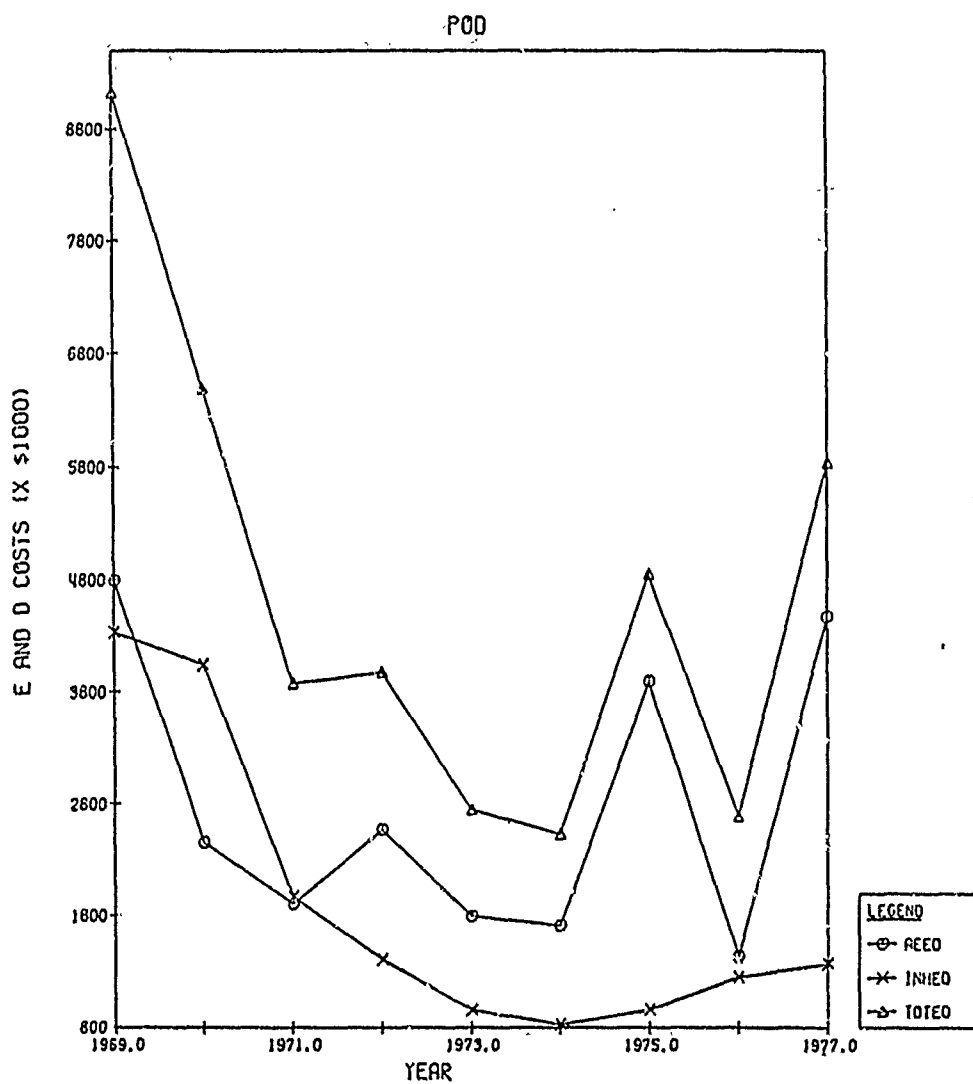
Figure B5.   E&D costs vs years - Omaha.
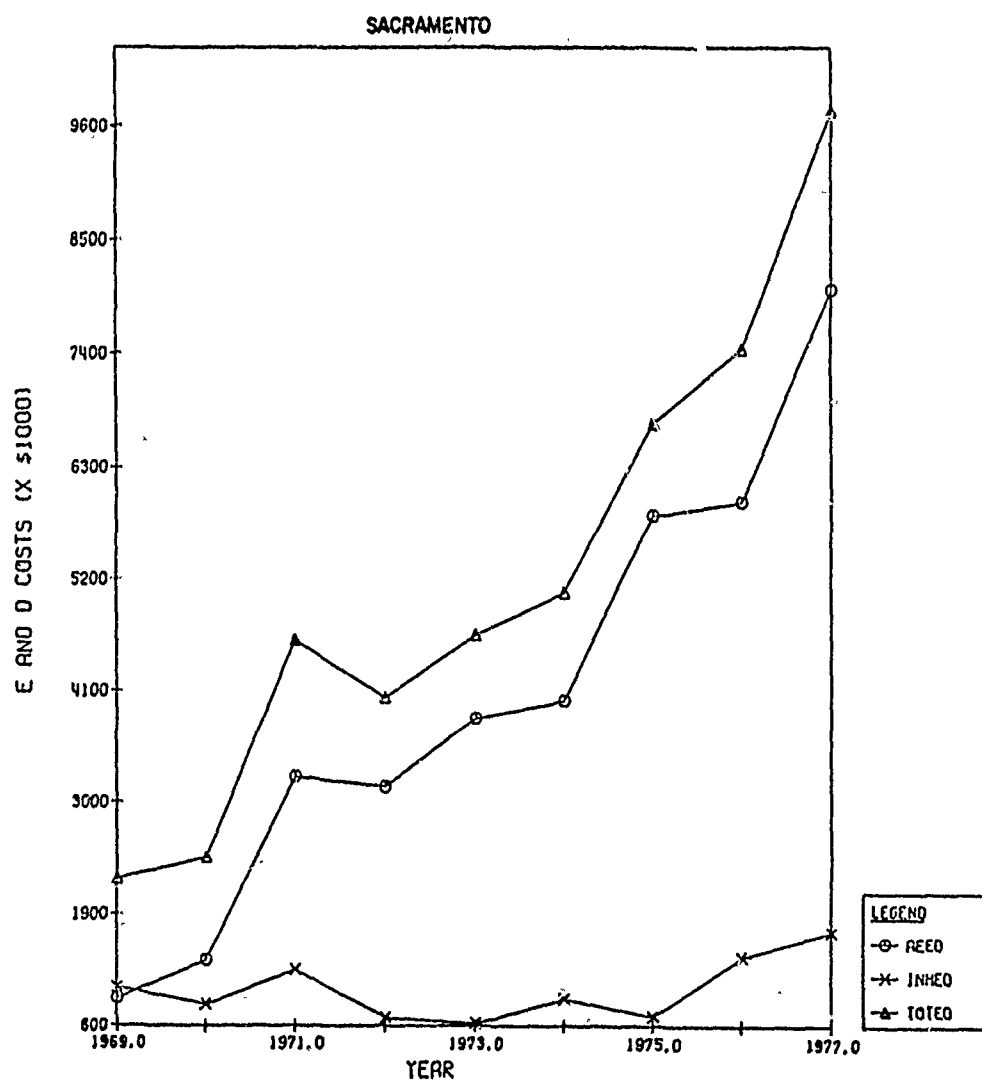
59

Figure B7. E&D costs vs years - Pacific Ocean.

60

Figure B8. E&D costs vs years - Sacramento.

61

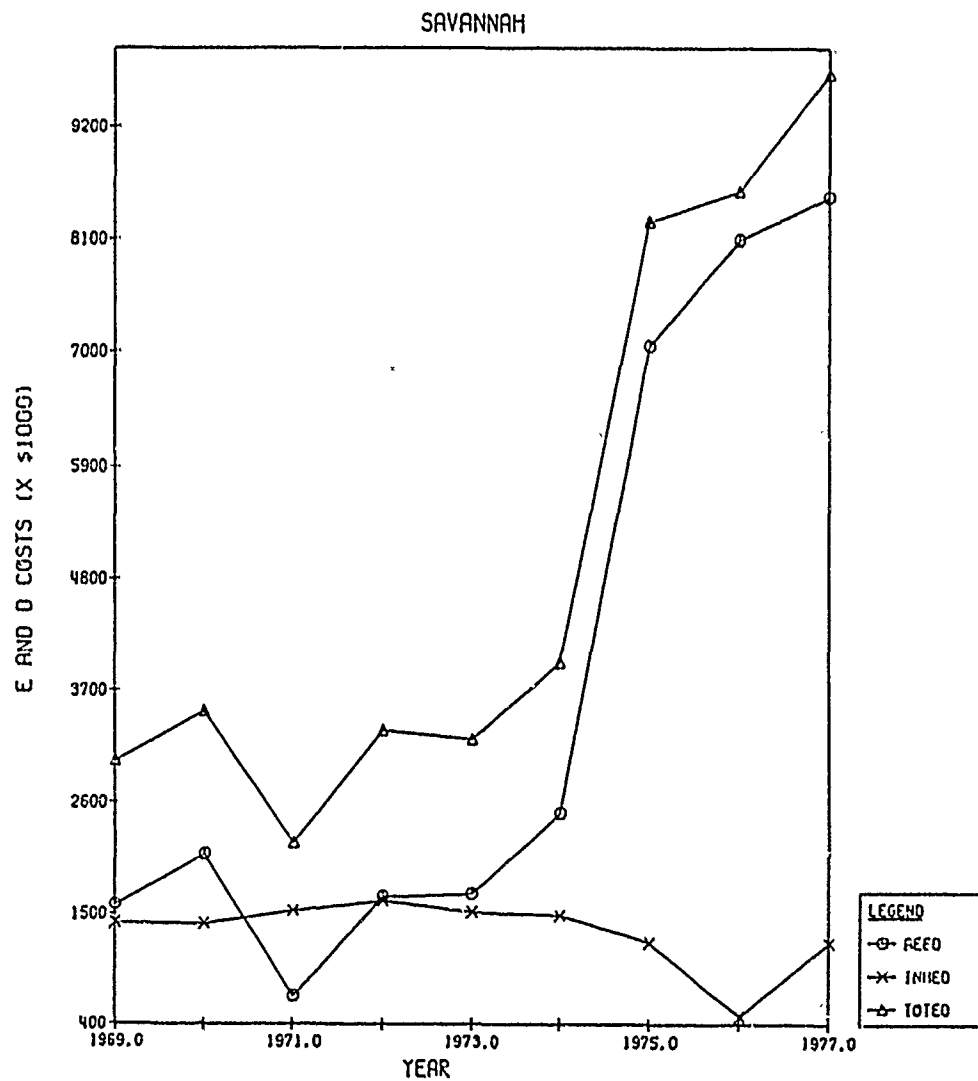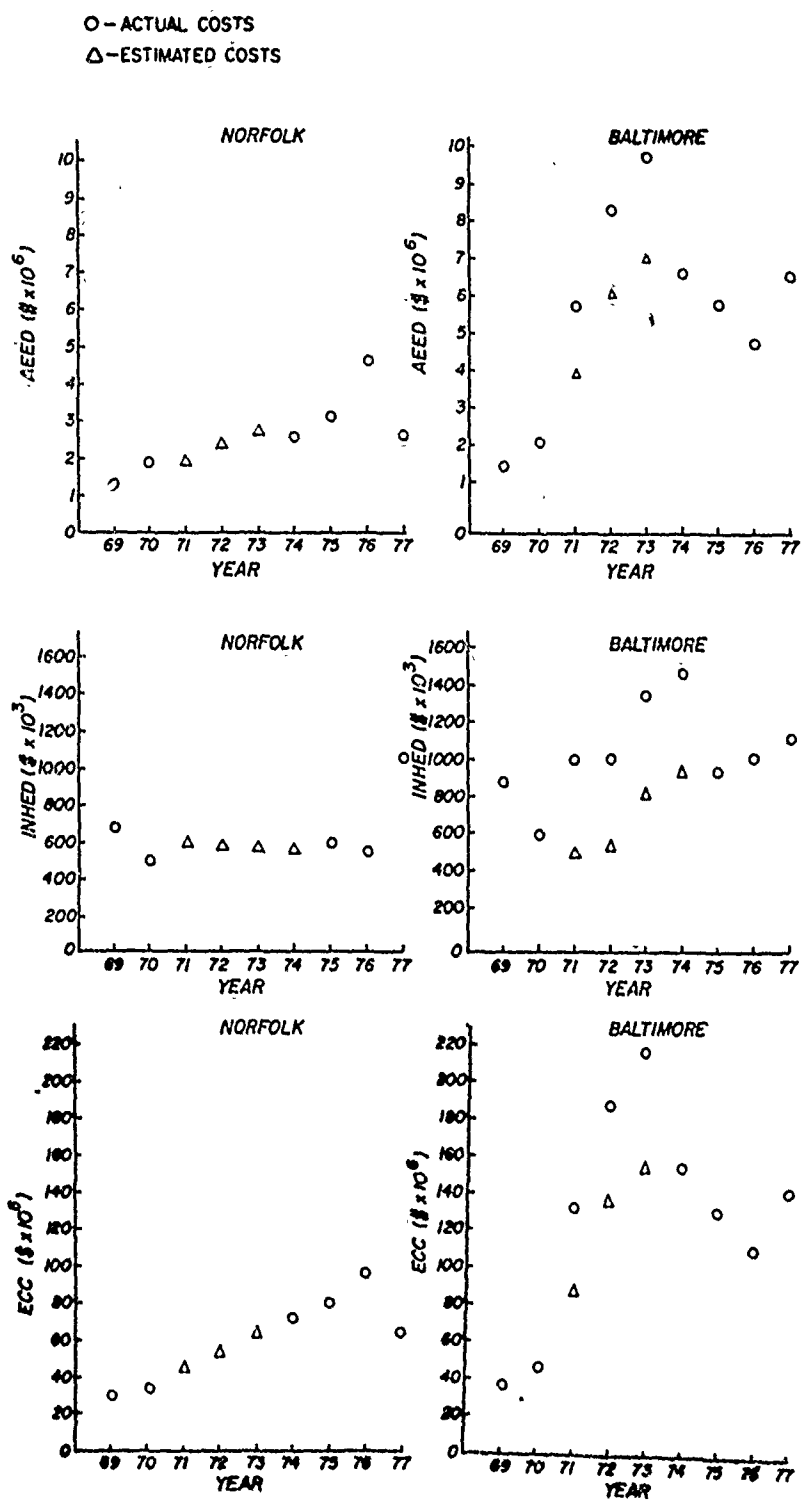Figure B9. E&D costs vs years - Savannah.

O – ACTUAL COSTS
△ – ESTIMATED COSTS

Figure B10. Data estimates/adjustments for Norfolk and Baltimore.

63
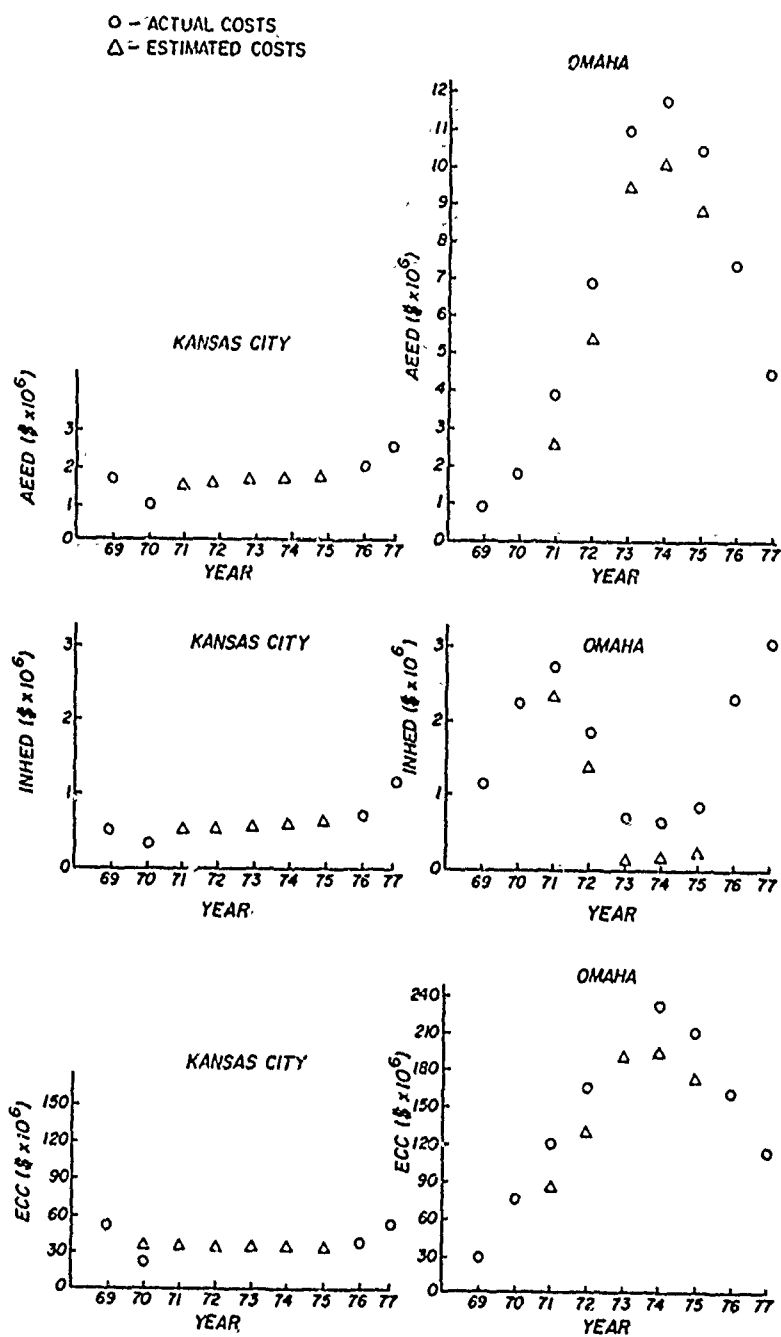
Figure B11. Data estimates/adjustments for Kansas City and Omaha.

64

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